To Stephen, from

Ethelbert Dowlen.

March 1911.

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E. Dowden
with the —
author's best
acknowledgments

PHOTOGRAPHED SPECTRA

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PHOTOGRAPHED SPECTRA

ONE HUNDRED AND THIRTY-SIX PHOTOGRAPHS OF METALLIC, GASEOUS, AND OTHER SPECTRA PRINTED BY THE PERMANENT AUTOTYPE PROCESS

WITH

INTRODUCTION, DESCRIPTION OF PLATES, AND INDEX

AND WITH

AN EXTRA PLATE OF THE SOLAR SPECTRUM (SHOWING BRIGHT LINES) COMPARED WITH THE AIR SPECTRUM

BY

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PHOTOGRAPHED SPECTRA.

INTRODUCTION.

During the course of the last and the preceding winters, I was led, in connection with an investigation bearing on the Spectrum of the Aurora, to take photographs of certain of the metallic and gaseous Spectra with a spectroscope of moderate dispersion. After a time this work gradually extended itself, and ultimately a very considerable collection of such photographic plates was obtained. In these labours I was very efficiently assisted by Mr. G. H. Murray of the Surrey Photographic Company (who superintended the photographic department), and by Mr. E. Dowlen of Guildford, to whom I am much indebted for notes and general assistance. The photographic impressions comprised all that could be obtained of the spectrum in each case, ranging from about *b* to beyond H^1 H^2 in the violet. It was soon apparent from an examination of the plates obtained,—

1. That considerably more of the spectrum was obtained in the direction of the violet end than is ordinarily delineated in the published works on Spectra.

2. That, notwithstanding the moderate dispersion and the limited extent of the spectrum obtained (for want of the red end), each individual photograph had, without actual measurement of its principal lines, a separate and distinct character, easily recognised when once seen, and distinguishing it from all others. This peculiarity we think will be borne out by an examination of the Plates produced, and we ourselves had several practical instances of its application in our process of taking the photographs.

Under these circumstances we considered we might, with probable advantage to others engaged in spectroscopic research, reproduce a series of our results as forming at once a handy book of reference to spectra in general, and as also illustrating in each particular case the peculiar features of the spectrum photographed.

The spectroscope employed (for the metals) was constructed by Mr. John Browning some years ago specially for Auroral observations, and is of the direct vision form.

The prism is an inch aperture compound (5) one, dividing very easily the D lines with a low eyepiece, a similar second prism can be slipped in for use if desired. The collimator carries an $1\frac{1}{4}$ achromatic lens of 6 inches focus. The ordinary observing telescope and eyepiece were removed, and an $1\frac{1}{4}$ achromatic projecting lens of 9 inches focus was substituted for them. The

short tube carrying the last-mentioned lens was connected by a black velvet bag, with an ordinary square camera for plates $4\frac{1}{4} + 3\frac{1}{4}$, and the images were taken upon collodion wet plates. (See Frontispiece for arrangement of apparatus).

The metallic spectra were obtained of two sorts:

1. By the spark.
2. By the electric arc.

The metals employed mostly formed part of a German cabinet which came into our hands with a good character.

For obtaining the spark spectra, the apparatus consisted of a large Rhumkorff coil, giving, with four double plate half-gallon bichromates, a thick strong spark about 2 inches long. In the circuit was introduced a condenser, composed of 4 glass plates, each containing 50 square inches of coating. By this condenser the spark was reduced to one from $\frac{1}{4}$ to $\frac{1}{2}$ an inch long, and of considerable brilliancy. The time of exposure in the case of the spark spectra varied very considerably, averaging perhaps 15 minutes.

For the arc spectra 40 pint Grove cells (except in one or two instances when 30 only were used) were employed, and with these the arc was steady and of sufficient length. In all cases the slit was placed vertically; and in our printed Plates we have followed the usual practice of spectroscopists, in keeping the red end of the spectrum to the left hand. Care was taken to have the carbon points and cups well cleansed, and by trial plates, taken from time to time, it was seen

that they contained no impurities affecting the spectrum.

For the spark, wires or points of metal, held by miniature steel pincers, were used.

In the case of the arc, sometimes fragments of the metals, sometimes the metal in powder, and in a few instances solid metal electrodes were employed. The time of exposure in the case of the arc ranged from three to five minutes, according to the intensity of the stream of light. The length and brilliancy of the arc were found to alter much according to the nature of the metal placed in the cup. The spark also varied considerably in length and intensity according to the electrodes. In the spark spectra, the air spectrum is, with a few exceptions, seen in company with the metal lines, the latter being, however, easily distinguished from the former by their passing only partly across the spectrum, while the air lines cross it entirely.

In the arc spectra some carbon lines of constant place seem the only foreign introductions into the system of metallic lines. These carbon or, as we called them, 'point' lines, are found useful in placing and comparing the several spectra when obtained. The images as thrown on the camera plate were rather more than two inches long; and these were subsequently enlarged exactly once. The lines required very careful focussing, the slit being in most cases fine, so that where lines are found thickened it is in general due to their character. To supply the want of an approximate scale, and also to indicate the part of the spectrum

photographed, I prepared a diagram in which two spectra of the metal manganese were respectively compared, and a scale obtained by direct interpolation. The upper horizontal spectrum was a photograph obtained from manganese in a rather weak arc (30 cells). The vertical spectrum was an enlarged (by photography) copy of Monsieur Lecoq de Boisbaudran's normal spectrum of chloride of manganese ('Spectres Lumineux, Atlas,' Plate xvii). The curve obtained was regular, and a subsequent comparison of the result with the solar spectrum of the same instrument (Plate xxi) is satisfactory. The scale in most cases fairly coincides for the principal lines with Monsieur de Boisbaudran's spectra, but instances will be found where the photographed spectral images are not in themselves absolutely uniform in exact length and position of fiduciary lines. The causes of this are not yet fully worked out, but we believe the result to be due to a difference in certain cases in distance of the discharge from the slit. To the Description of the Plates are added some notes by way of information as to the behaviour of the metals and on other points.

The wave lengths of lines (where given) are taken partly from M. Lecoq de Boisbaudran's work, 'Spectres Lumineux,' and partly from Dr. Watts' 'Index of Spectra.' The photographs were all taken on separate plates, and have been very well reproduced and printed in permanent pigments by the Autotype Company, in compared sets of four. They are for convenience arranged in alphabetic order,

the upper metals in the plates being selected for arrangement where electrodes of different metals were employed. Spark and arc spectra of the same metal are in many cases compared. A few of the metals and metalloids are wanting, mainly from the difficulty of obtaining with our apparatus, spectra bright and permanent enough to impress images on the photographic plates. The arc photographs might with advantage bear considerably greater enlargement, but it was thought convenient to keep them, for the purpose of comparison, of the same size as the spark spectra. Some of the metals do not show their full set of lines, probably for want of more coil power; but there were considerations why a moderate spark was originally selected, and the spectra were subsequently kept uniform in this respect.

When rough lumps of metal were used for points the spark was generally winged (especially when the batteries were fresh), and played about over the surface of the metal. The wings of the spark were tinged with green in the case of silver and copper, with red in that of iron, white or bluish white with magnesium. Titanium ore gave occasional flashes of red (probably from the iron clips), sodium gave a bright yellow flame. The cups used with the spark apparatus were of aluminium, except where glass is mentioned.

Width of slit averaged ·003 inch, except in one or two instances which are especially mentioned.

When different metals were used as terminals, the current was generally reversed in the middle of the exposure.

The carbon terminals used in the arc were cut from ordinary gas carbons, 3 centimètres long and 6 millimètres square. Those for the negative pole had one end filed to a point. Those for the positive pole were hollowed out at the end with a drill so as to form a cup. To get rid of impurities (of which iron formed the principal part), the carbons were soaked alternately in acids and water: First, they were soaked in diluted sulphuric acid, 2 parts water, 1 acid, then soaked in water. Secondly, in dilute nitric acid, equal volumes of acid and water. Thirdly, in hydrochloric acid, half volume of water. The acids and water were changed several times during the soaking. Last of all, the carbons were soaked in water alone, which was repeatedly changed until all the acid was washed out. They were then slowly dried in an evaporating dish over the flame of a Bunsen burner. The acids were all pure, and the water distilled. The whole process occupied from one to two weeks, according to the density of the carbons, some being more porous than others.

Many of the carbons broke during this treatment. C.D.

When metals in powder were used in the arc, small beads of the metal were usually scattered over the inner surface of the cup, the main portion of the metal remaining at the bottom.

All the metals of the iron group gave out sparks, viz., manganese, iron, cobalt, nickel, chromium, and uranium. Silver gave a melted bead, which revolved in the carbon cup without actual contact with it. The width of the slit was generally ·001 inch, distance of arc from slit 1½ inch, but from the flame playing round

the point and cup, this distance was subject to variation. The adjustment for distance of arc discharge was by rack work worked by hand. The upper carbon was fixed in a ball-and-socket joint so as to adjust easily over any part of the cup.

A fresh pair of carbons was used for each metal. Much trouble was found in keeping the slit, and the slit plate clear from metallic beads and other impurities. It would be a great advantage for future similar work to have the whole slit plate gilded and the slit jaws formed of obsidian, platinum, or gold.

The gas spectra are represented in the last fifteen Plates; and for the purpose of obtaining these it was found necessary to resort to a different form of instrument to that employed for the spark and arc spectra.

An attempt was at first made to take all the spectra with the same instrument, but it was soon found that less dispersion and a brighter image would be required to give any useful results with the gases, and one only of the series (viz., spark in coal gas), was taken with the same instrument as the metals.

Three forms of instrument were then arranged and used for gaseous spectra :—

A—A compound (5) direct vision prism on stand similar to that used for the spark and arc spectra, but the collimating and projecting lenses of the spectroscope were replaced by two camera lenses of somewhat larger diameter, and each of $4\frac{1}{2}$ inches focus. The image was fairly bright, but not very sharp, as the slit could not be made very fine without loss of light.

B—A table spectroscope constructed for me by Mr. Browning with two quartz (inch) prisms of 60° angle, the collimating and projecting lenses being also of quartz $1\frac{1}{4}$ inch in diameter, and of 6 inches focus. The images with this instrument were brighter than those with the last instrument (A), were of fair definition, and penetrated more into the violet.

C—This last instrument was also a table spectroscope, made for me by Mr. Browning, with a view to the photographing faint spectra.

The prism is a large compound (3) one, $1\frac{1}{2}$ inch high, 2 inches across and $4\frac{5}{8}$ inches in its longest base. The collimating and projecting lenses are from a fine field glass 2 inches in diameter and of 7 inches focus. Our experience led us to conclude that considerable aperture of prism and of lens was absolutely essential for the production of bright and sharp images. This Mr. Rutherford had previously demonstrated in America. The images from our instruments of small aperture bore no comparison whatever with those afforded by the larger instrument now describing. With the latter the images were very bright, and the lines wonderfully well defined and separated for so small an amount of dispersion. The impressions are quite small on the photographic plate (less than half an inch in length), but so sharp that they would bear enlarging nine or ten times without material loss of definition.

In the Plates of the gases the images obtained from spectroscope A are enlarged twice, those from spectro-

scope B, (quartz), are also enlarged twice. Those from spectroscope C are enlarged rather more than five times.

The spectra from A and C spectroscopes are enlarged so as nearly to correspond in dispersion and in actual dimension. Those from the spectroscope B (quartz) are on a smaller scale altogether, and are mainly used where comparison of spectra is desired.

The spectra of the gases (except in one or two cases) were obtained from the exhausted tubes of the Geissler form commonly used in spectroscopy, some of foreign, some of home preparation. The latter were found best adapted for our work, being larger in the bore and bulbs, and bearing stronger currents without injury. For working the tubes, two different coils were used. The smaller one was a half-inch coil such as is generally sold for the purpose of lighting up tubes in spectral work, and was excited by a quart bichromate. The larger coil was that employed for the spark spectra before described; it was worked by two half-gallon bichromates only. This instrument has a large heavy break of the common form, but with screw adjustments enabling the rate of vibration to be easily controlled during work; a very steady current was obtained by this means. The smaller coil was used for single tubes; and such as would light up easily. The larger coil was used in cases where two tubes were employed, for line spectra and for tubes which required much lighting up. When line spectra were wanted, the condenser before mentioned with two plates taken out, or a small Leyden jar was introduced into the circuit, the

rate of discharge being regulated by the distance between two platinum points on a stand, which formed part of the connections. When the large coil was employed for a single tube, a second larger tube was usually introduced into the circuit to diminish the heating effect of the current. The time of exposure for the tubes was about twenty minutes with spectroscopes A and B, and from twelve to fifteen minutes with spectroscope C. The tubes which lighted up most easily and were not damaged by the continuous current, were nitrogen, carbonic acid, coal gas, cyanogen, hydrogen, oxygen, silicic fluoride, and olefiant gas. All these photographed more or less easily. The tubes which gave us more trouble were bromine, iodine, chlorine, ether vapour, turpentine vapour, sulphur, and tin chloride: bromine and chlorine we failed to get photographs of. These tubes broke down before they had been lighted a sufficient length of time to impress an image. Iodine vapour tube failed also in this respect; but we succeeded in photographing (though not well) the spectrum of the spark in a bulb filled with iodine vapourised. The tin chloride tube also soon broke down, and we obtained only one plate from it. Further particulars of the behaviour of the tubes will be found in the Description of the Plates. In all cases a photograph was first tried of the single tube as filling the whole length of the slit, this last being intentionally as long as the instrument would bear. When the slit was reduced in length, whether by the comparison prism being used or in any other manner, a

manifest falling off of the photographic effect in point of brightness of image was apparent. It was only with the instrument C that we could use quite a fine slit. In the course of our experiments we tried the effect of an electro-magnet upon some of the tubes. Our magnet was one of Ladd's, of the size used for dia-magnetic experiments, with arms $10\frac{1}{2}$ inches long and poles 2 inches across and with large movable coils of insulated copper wire. It was excited by the four half-gallon bichromates before referred to. Probably with more battery power we should have obtained changes in the spectra themselves in accordance with the experiments of Monsieur J. Chautard. It was, also, unfortunate that chlorine, bromine, iodine, sulphur, and tin chloride, from which he obtained his best results, were just the tubes which gave us the most trouble in a photographic way. The magnet was fitted with conically pointed armatures; between the points of which we placed the capillary part of our tubes. In this way danger arose to the tubes, as the armatures when the current was passing would draw together with sufficient force to crush the glass. We secured the armatures in their places by turning out circular edges on their bases, and so arranged that the blunted points would just take the thickness of the tube between them. Our experiments were mainly without much in the way of positive results. The stream of light was in most cases narrowed, and appeared to experience a certain amount of resistance in its passage (in the case of silicic fluoride a sort of sharp whistling sound was

heard when the magnet was excited), but we did not detect any palpable change in or addition to the spectral lines. Only in the case of nitrogen did we get any very marked effects, and this was somewhat peculiar as M. Chautard classes this gas amongst those upon which 'the influence of the magnet is hardly perceptible,' ('Phil. Mag.' S. 4, vol. 50, p. 79). A Geissler nitrogen tube having been placed between the poles of the magnet, it was lighted up by the small coil. The stream of light was steady and brilliant, and (except at the violet pole) of the rosy colour peculiar to a nitrogen vacuum tube. On the excitation of the electro-magnet the discharge at once appeared diminished in volume, with an apparent increase in impetuosity ; and not only the capillary part but in a less degree the bulbs also of the tube changed from a rosy to a well-marked violet tint. We several times connected and disconnected the magnet with its batteries, but always with the same result.

This effect of shifting tint was very striking, and assuming the Aurora to be wholly or in part of electric origin, is strongly suggestive of a reason for the varying tints of the streamers which are frequently observed. Of the spectrum of the capillary part of this tube we took two plates, taking care that all things should be as equal as possible, the apparatus undisturbed, and the time of exposure exactly the same. One plate was taken while the tube was in its normal condition, the other while the tube was influenced by the magnet. The plate + magnet will be seen to penetrate more into

the violet, though the character of the spectrum itself does not appear altered. An eye-view of the tube with the spectroscope also showed us no definite variation in the spectrum, nor could we trace that the violet pole spectrum extended itself under the altered condition of the tube as to tint. We tried also a large bulb Plucker tube in which the aura from the violet pole was condensed into a bright arc under the influence of the magnet. No change of the violet tint was here remarked, but only a brightening of the light consequent upon its condensation. Plates in this case also gave slightly more of result in the violet. In the case of silicic fluoride the stream of light was diminished in volume, and the plate from the tube without the magnet is decidedly the brightest. In other respects the plates are alike.

Our experiments of course do not conflict as compared with M. Chautard's, as the battery employed on our magnet was far inferior in power to his (he used from twelve to fifteen large Bunsen elements), but our experience with regard to the nitrogen tube seemed worth recording.

In taking our spectra, and specially the gases with spectroscope C, we had to exercise great care in the focussing on the plate. For this purpose the finest ground glass for the plate and a strong magnifier to view the image were employed. The rough adjustment was first of all obtained by moving the camera on its heavy base, and the fine adjustment was then completed by means of a screw motion in the same

base. It must not be supposed that the Plates printed were all we obtained, probably not more than one in three which were taken were selected for enlargement.

In nearly all cases we took two plates of the same spectrum, although the first might be good; and frequently from the heat of the room and other causes plates good as to spectral image were imperfect as photographs. In fact anyone wishing to try the same work on the same or a larger scale must expect partial failure and disappointment, until experience has been gained in it. Kennett's dry plates would have some advantages over the wet plates we employed, but they would also be subject to the drawback of taking longer to develop, so that except with the loss of much time, one could not, as we did, develop and examine the plates obtained at once and before the points and other apparatus were displaced for a next experiment. Our results of course are not intended to be placed by the side of photographs of spectra of larger dispersion taken for comparison of the metals, study of the solar spectrum, etc., but they may perhaps prove useful to amateurs and others, working with spectroscopes of small dispersion, for comparison of spectra in their general aspect, and for study of the points and peculiarities attaching to most spectra, which are generally brought out in our prints. To those who have the time and opportunity there seems much to invite a taking up of the whole subject on a more extended scale and with more complete apparatus.

Absolute truth is everything in spectroscopic work,

and the very best draftsman working with the most perfect micrometer cannot, even at the expense of a vast amount of labour, equal in accuracy a good photograph of a set of spectral lines. Photographs, too, have the great advantage that they may be enlarged and tested at leisure; and if several plates of the same spectrum are taken and subsequently compared, the investigation for certainty of result is only a matter of time and trouble.

I ought to mention that we tried in the case of the spark spectra (but without advantage) tinted collodion, with a view to work more towards the red end. The tinting substances used were Magenta, Judson's Violet, Annatto, Saffron, Turmeric, and Chlorophyll. Dr. Huggins' success in stellar photography with Iceland spar prisms promises a considerable extension of the spectrum in the ultra violet direction, and some recent investigations of Captain Abney and others work in the direction of the yellow and red regions, so that there is good hope of obtaining at no distant date a wide range of photographs including all of the visible spectrum, and more. Of what assistance such faithful light pictures would prove to science, I need not here point out, except as an apology for our present attempt to popularise a subject hitherto somewhat of a sealed book confined to the laboratories of workers in special research.

DESCRIPTION OF THE PLATES.

PLATE I.

First Print. *The Scale.*—The scale has been already referred to in the Introduction. The photographs of the metals are so masked that in general when the scale is applied to them, it falls in its right place or very nearly so. To enable, however, the scale to be applied with greater exactness two fiduciary marks or points are indicated upon it, the one a bright line marked 'spark' situated between *b* and F, the other a set of seven carbon or point lines between G and *h* marked 'arc.' For the spark spectra the scale is adjusted by applying the bright line marked 'spark,' to the bright line which appears prominently at the left hand of each spark spectrum. To adjust the scale for the arc spectra the set of lines marked 'arc,' are to be applied to the corresponding set of lines which are to be distinguished in most of the arc spectra towards the violet end, and which are the principal ones derived from the points and are considered as carbon or carbon compounds. Two prints are given of the scale, one on Plate I., and the other on Plate XXI., so that if direct

application and comparison are desired one of them may be cut out and used for the purpose.

SECOND SPECTRUM. *Air with wide slit.*

THIRD SPECTRUM. *Air with fine slit.*

These two spectra may be described at the same time. They differ only in length of the spark (which was taken between platinum points) and width of the slit.

The lines comprised in them may be traced more or less throughout all the spark spectra, and form useful indices for position of metal lines.

Lecoq de Boisbaudran gives [Spectres Lumineux, PLATE II., Etincelle longue], a spectrum comprising lines (with others) 5003, 4805, 4706, 4648, 4633, 4449, 4434, 4347, and a band at 4240. This spectrum resembles generally our present spectrum, though it fails to agree in some respects, probably from the introduction of the condenser in our case. Our spectrum is for the stronger lines, identical with that of the line spectrum of the capillary part of a nitrogen tube. (See PLATE XXV. Fourth Spectrum).

FOURTH SPECTRUM. *Arsenic Spark.*—Small rough lumps of the metal placed in the clips. Spark white, and striking with ease across a considerable distance. Slight fumes of oxide at first, exposed twenty minutes. Two plates taken which were strictly identical, each showing the fuzzy bands on the margin of spectrum midway between F and G from about 4575 to 4475, and the lines in the bright part of the spectrum about 4400, 4355, and 4310. Dr. Watts, in his 'Index of

Spectra,' does not continue the spectrum of Arsenic beyond 5324 towards the violet; but faint lines are, given on Huggins' authority, at 4551, 4537, 4497, a stronger one at 4464 and faint ones at 4369 and 4335.

PLATE II.

First Spectrum. *Aluminium Spark.*—Pieces of the metal in clips. Spark moderate in length, ten minutes exposure; also tried with condensing lens in front of slit. Slit rather wide.

Second Spectrum. *Aluminium Arc.*—Piece of metal cut from small bar, in carbon cup. Arc short, slit fine.

Principal line in the spark spectrum at about 4500. This is represented in the arc by the edge of one of three sets of shaded bands.

The two very conspicuous lines in the arc, between H^1 and H^2, are only represented by one near H^1 in the spark. The edges towards the violet of the shaded bands in the arc are given by Lecoq de Boisbaudran [Plate XV., Aluminium métallique], at 4845, 4652, and 4478. And the intense lines between H^1 and H^2 at 3962 and 3943, (H^1 is given in Watts' 'Index' at 3968 and H^2 at 3933).

Third Spectrum. *Antimony Spark.*—Rough lumps of metal in clips. Spark bright and broad.

Fourth Spectrum. *Antimony Arc.*—Small pieces of metal in carbon cup, arc of moderate length, much oxide formed.

The spark spectrum is peculiar owing to the stream of light running along each margin of the spectrum, apparently thickening at each extremity, not only the metal, but also the air lines. Some of the air lines however escape; proving that the appearance has not to do with the slit, but must be caused by metallic vapour hanging about each pole. (See also Lead and Antimony, Plate X., Fourth Spectrum.)

The arc spectrum gives little beyond the point lines. We took several plates, but always with the same result in this respect. The lines given by Lecoq de Boisbaudran, [Plate XXIII., Proto-chlorure d'Antimoine], are 5037, 4947, 4877, 4787, 4711, and Dr. Watts continues with 4693, 4588, 4349, and 4264. (See Lead and Antimony before referred to, where the lines are somewhat more distinct.)

PLATE III.

First Spectrum. *Bismuth Spark.*—Pieces of the metal in each clip, exposed ten minutes, spark bright.

Second Spectrum. *Bismuth and Nickel Spark.*—Pieces of metal in clips, exposed ten minutes, current reversed at half. Note extension of metal lines in the middle of the spectrum, in consequence of breaking away of the point.

Third Spectrum. *Bismuth and Tellurium Spark.*—Pieces of metal in clips, exposure ten minutes, current reversed at half. Tellurium partly fused, spark struck over Tellurium to the clip, (notice some iron lines from

the clip projecting beyond centre of the spectrum at Tellurium pole).

FOURTH SPECTRUM. *Bismuth Arc.*—Piece of metal in carbon cup, arc moderate.

The spectrum of bismuth with spark obtains easily, and the lines are well marked, those in the centre of the spectrum widening out considerably and showing in strong contrast to the air lines.

Lecoq de Boisbaudran gives (PLATE XXII., Chlorure de Bismuth), 5209, 5144, 5123, 5049, (4965, 4882), 4724 (characteristic), 4303, 4259, 4118 (characteristic).

Most of these lines appear in our spark spectrum, with others in addition.

The principal lines in our arc spectrum are about 4750 (very bright), and 4120 (probably Boisdaudran's 4118). The vivid lines in the bright part of the spark spectrum do not appear in the arc.

As to the second spectrum (Bismuth and Nickel), Lecoq de Boisbaudran gives [PLATE XIX., Chlorure de Nickel], lines at 4873, 4867, 4856, 4832, 4808, 4788, 4762, 4755, 4732, with principal ones at 4715 and 4401. Our spectrum extends more into the violet, and shows a very bright line near H^1.

The Tellurium spectrum will be referred to in its order further on.

PLATE IV.

FIRST SPECTRUM. *Barium Spark.*—Small pieces of metal in the clips which fused away rapidly, spark

bright. Spectrum peculiar as containing so little trace of the air lines, and for the fuzzy expansion of the principal lines. The lines generally are not confined to the margin, but cross the spectrum. Lecoq de Boisbaudran (PLATE VII., Chlorure de Barium dans le gaz) gives bands at 4974, 4873, 4794, and a barely visible line or band somewhat beyond. Dr. Watts gives bright lines or bands 4934, 4898, 4553, 4524, and 4130. From an examination of these last, I think that our spectrum (for want of the air lines) has been somewhat wrongly positioned.

If the Scale be advanced a little to the right, so that the second bright line in the spectrum coincides with 4898 (4900) on the Scale, the other lines will be found to fall fairly into their places, in accordance with Dr. Watts' figures.

SECOND SPECTRUM. *Beryllium* (Glucinum) *Arc.*—Metal in powder in carbon cup. Arc short. Dr. Watts gives two bright lines for Glucinum, 4572 and 4488.

These are not prominent in our spectrum, which is chiefly characterised by the bright lines between 'spark' and F, and by other fine lines scattered through the spectrum. The spectrum, however, bears so great a resemblance to meteoric iron and meteorite (PLATE X.), that there was found reason to suspect iron as forming the principal part of it. Upon testing the metal powder, it was found to contain iron as an impurity in considerable quantity.

THIRD SPECTRUM. *Boron Arc.*—Graphitoid in carbon cup. A dense glass-like crust of oxide formed

on the upper carbon, which interfered with the current, and had to be frequently cleared off. Arc short and uncertain. The evidence of the spectrum is mainly towards the red end, where absorption bands seem traceable.

FOURTH SPECTRUM. *Calcium Spark.*—Pieces of metal in the clips inclined to fuse quickly. Spark fairly bright. This failed as a Calcium spectrum. The principal lines, a double one at about 4935, and others at about 4830, 4750, 4710, and 4060, are those of zinc. Upon testing the specimen of the metal, zinc was found present in considerable quantity.

PLATE V.

FIRST SPECTRUM. *Cadmium Spark.*—Small pieces of the metal in clips, exposure moderate, plate rather weak, but clear of air lines.

SECOND SPECTRUM. *Cadmium Arc.*—Pieces cut from small bars in carbon cup. Clouds of yellow oxide formed. Arc moderate. Metal burnt away quickly, Lecoq de Boisbaudran [PLATE XX., Chlorure de Cadmium], gives principal lines at 5085, 479[illegible], 4677, and a moderate one at 4414.

These three principal lines appear in our arc spectrum, with an additional conspicuous line about 4060. A line inflated at each end also appears at about 4425 in the spark spectrum, which may be Lecoq de Boisbaudran's 4414.

THIRD SPECTRUM. *Arc between Carbon points.*

Fourth Spectrum.—A paper print from the plate of Spectrum 3, with all the lines which could be in any way seen on the glass negative ruled out.

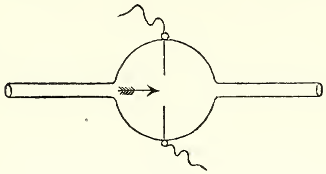
A description of the preparation of the carbon points has been already given in the Introduction. The Third Spectrum is an example of the plates obtained from the points alone. This plate contains, besides those that show in the print, a number of very faint lines seen only when it is held up to the light.

A good paper print was obtained from this plate, and on this was ruled out all the lines that could be traced on the negative. A reversed copy of this is shown in the Fourth Spectrum. The lines are presumably those arising from the points, and a peculiarity of our arc spectra in general seems to be that while these lines are all more or less present in each arc spectrum, the number and intensity differ much. They appear also to depend for number and intensity, to a considerable degree, upon the metal or other substance burning in the arc, so that spectra of the same metal almost invariably contain, in addition to the metal lines, point lines of the same extent and character. It is this fact that seems to give to each spectrum its individuality referred to in the Introduction.

PLATE VI.

First Spectrum. *Spark in Coal Gas.*—For this spectrum the same spectroscope was employed as in the case of the metals. A glass tube with a bulb

blown in the centre, of the form here shown ($\frac{1}{4}$ size), with platinum wires fused into the bulb was selected



to pass the spark through. One end of the glass tube was connected, by means of elastic tubing, with the gas jet in the room. The other end of the tube was also joined to tubing which conveyed the gas out of the room into the air, after passing through the bulb. The two platinum wires were connected with the large coil and condenser, and while the spark was striking across the bulb (vertical with the slit) a current of coal gas at ordinary pressure was kept flowing through the tube. The spark was bright and slightly blue in tint. Carbon was soon deposited on the bulb. The spectrum shows a set of carbon lines, the two brightest at about 4580 and 4220, and also the hydrogen line *h* considerably expanded. This last line also has the appearance of being either double, or reversed, in the centre. The line 4220, and its accompanying group of fine lines on the right, occupy about the same place as a set of bright lines in the arc spectrum. They are however not identical, the lines in the coal gas diminishing in distance from each other towards the bright line, while in the arc the lines diminish towards the violet, (see a better enlargement of this negative on Plate

XXVI., Second Spectrum). It is curious that we obtained this sharp line spectrum on only one occasion, though we subsequently took several other plates under similar conditions of apparatus and spectroscope.

In the subsequent plates the line 4580 was replaced by a misty band, with a double or reversed appearance similar to the hydrogen line in our plate. Of its accompanying set of lines towards the violet, one only, the detached one nearest to the violet, remained. Line 4220 nearly disappeared, and remained only misty and indistinct; while the group lines accompanying it were quite gone, and a bright broad band reaching to the hydrogen line took their place.

The hydrogen line *h* was not so much expanded as in our spectrum, and a continuous spectrum crossed by two narrow bands or broad lines, and two other faint lines (Hydrogen?) appeared beyond it towards the violet. See also a plate of the same spectrum taken with the gas spectroscope C, Plate XXVII. Second Spectrum, and a print from the original plate, from which the present enlargement was made, Plate XXXIII. Fourth Spectrum.

The plates of the subsequent spectra before described were altogether more misty and less defined than our first spectrum.

Second Spectrum. *Chromium Arc.*—Metal powder in carbon cup, some scintillation during combustion.

Lecoq de Boisbaudran gives [Plate XVI., Sesquichlorure de Chrome], a very bright line at 5205, a double one at 4649, a band of indistinct rays at 4343,

and three well-marked lines at 4290, 4275, and 4255. The line 5205 does not appear in our spectrum, (the outside line towards the red is a carbon one). The other lines are easily distinguished.

A set or band of close lines is also to be noticed at about 4540.

Third Spectrum. *Cobalt Arc.*—Small piece of metal in carbon cup, arc moderate. Lecoq de Boisbaudran [Plate XIX., Chlorure de Cobalt] gives a list of twenty-one lines in the part of the spectrum comprised in our photograph, distinguishing for brightness 4868, 4840, 4815, and 4533. In our spectrum the lines show pretty much of equal intensity, and it is somewhat difficult to separate them from the carbon lines.

Fourth Spectrum. *Copper Spark.*—Small pieces of wire, spark tinged green, spectrum poor, principal line crosses a part of the air spectrum deficient of bright lines, at about 4280.

PLATE VII.

First Spectrum. *Copper Arc.*—Stout pieces of copper wire used as terminals, arc narrow, brilliant green in tint and of moderate length.

Second Spectrum. *Copper Arc.*—Small bead of prepared wire, an alloy of gold, silver, and copper in the carbon cup. The wire was prepared by a jeweller as an equal part alloy of pure gold and silver, but it subsequently proved that the gold was adulterated with copper.

(*Note.*—The images of these two spectra are not of the same actual size, the carbon arc being somewhat the larger, and allowance must be made for this in comparing them with each other and with the Scale).

In the case of the alloy, the copper, though so inferior in quantity, seems to have mainly appropriated to itself the spectrum. The gold and silver lines are very faint, but they may be traced by comparison with the spectra of these metals. (See also PLATE XV., Spectrum Silver and Copper Arc, where copper again monopolises the spectrum).

Most (but not all) of the lines in the First Spectrum appear in the Second Spectrum, mixed with a few of the principal carbon or point lines. The bright single line about 4400 in the first spectrum appears double in the second spectrum.

The very conspicuous double line in the first spectrum at about 4075 is replaced by a single bright one, with faint companion in the second.

Lecoq de Boisbaudran gives [PLATE XXIV., Chlorure de Cuivre en solution], a long list of copper lines, including the three characteristic ones (5218, 5153, and 5106), seen on the extreme left of our spectrum.

He also gives on the same plate the spectrum of Chlorure de Cuivre dans le gaz, with brighter groups towards the violet. These spectra do not in general character accord with ours.

THIRD SPECTRUM. *Didymium Arc.*—Powder in carbon cup, arc short, spectrum full of many coarse

lines of the same character; with traces, especially towards the red and the centre, of absorption bands. The carbon lines are either absent or so obscured by the metal spectrum as almost to cease to serve as guides in masking. Lecoq de Boisbaudran gives [PLATE XIII.] two absorption spectra of Didymium, neither of which readily compares with ours in lines or character.

FOURTH SPECTRUM. *Erbium Arc.*—Powder in carbon cup, a bead of the fused metal insisted on adhering to the negative pole, the arc being then longer than when the metal remained in the cup. When the metal was burnt in the cup the arc was brightest. The spectrum is characterised by a considerable number of bright lines, with many very fine ones between; the carbon lines are also in this case either absent or very much obscured, so that position on mask is doubtful. Lecoq de Boisbaudran gives [PLATE XIV.] a spectrum of 'Erbium emission,' which does not assist in examining ours. Dr. Watts gives a joint spectrum of Erbium and Yttrium, with some lines common to both metals. Our spectrum of Erbium does not accord with that of Yttrium, PLATE XIX., in lines or general character. We found in our cabinet, a specimen labelled Terbium, of which we also photographed the spectrum. On comparing it with our present spectrum of Erbium, (except that the one spectrum has a little less glare than the other) the two spectra were found absolutely and line for line coincident.

Every line is exactly repeated in each plate, and the relative intensities of the lines are preserved in each spectrum in the most accurate manner.

PLATE VIII.

First Spectrum. *Gold Arc.*—Small lumps of metal in the carbon cup. Arc short. Spectrum fairly clear of point lines. Lecoq de Boisbaudran gives [Plate XXVI. Chlorure d'Or en solution] lines at 5063, 4812, 4793, 4608, 4490, 4437, 4338, 4314, 4064. The lines 4812 and 4064 are recognised in our spectrum, as also a strongish line about 4570.

Second Spectrum. *Indium Arc.*—Small piece of the metal cut from bar in carbon cup, arc moderate, spectrum with a good deal of glare, point lines indistinct. Two principal broad and expanded metal lines read off at about 4515 and 4100, (Lecoq de Boisbandran gives Plate XXI., Sels d'Indium, 4511 and 4101). For spark spectrum of Indium, see Plate XVI., Third Spectrum.

Third Spectrum. *Iridium Arc.*—Piece of metal in carbon cup. Arc short. Spectrum bright. Point lines long in centre. Note group of very fine lines at extreme left towards the red, (centre about 4990) with two dark spaces to right of them, also two bright lines about 4550. Dr. Watts gives a spectrum of 'Iridium, and Ruthenium,' with lines (Kirchhoff) 6347, 5449, and 5299. For our spectrum of Ruthenium, see Plate XIV., Second Spectrum. The two spectra certainly have a very close general resemblance. Note the group of four lines towards the red end and the outlying short line at the extreme violet end, common to both.

Fourth Spectrum. *Iron and Copper Spark.*—Wires of the metals in the clips, condensing lens, in front of slit, slit wide. Image rather coarse. Iron lines projecting in several places beyond the upper edge of the spectrum. Copper line at about 4280 seen projecting on lower edge of the spectrum.

PLATE IX.

First Spectrum. *Copper and Iron Spark.*—Same as last (Iron and Copper), but metals reversed in clips, no condensing lens, slit wide and image confused, but lines can be traced through the glare.

Second Spectrum. *Iron Arc.*—Reduced powder in carbon cup. Arc moderate, much scintillation. Thirty cells Grove only used, slit rather wide. Spectrum imperfect, but introduced to show how battery power may vary general aspect of the spectrum. Note broad dark space about centre of spectrum, also glare of light towards the red, with group of lines at extremity of spectrum in that direction.

(This spectrum is not positioned to the Scale, but can easily be compared by eye with the next).

Third Spectrum. *Iron Arc.*—Reduced powder in cup forty cells Grove. Slit fine. Spectrum much more uniform than last, point lines absent or indistinct.

Lecoq de Boisbaudran gives [Plate XVIII., Perchlorure de Fer en solution Etincelle] a spectrum comprising a set of groups of lines in the violet separated from those at the other end of the spectrum by a

blank space. This blank space is also seen in our photograph separating the four characteristic lines towards the red end of the spectrum from the main body of lines towards the violet.

The lines towards the red in our spectrum evidently correspond with Lecoq de Boisbaudran's 4959, 4923, 4891, and 4874. Our spectrum is slightly out of position on the mask; but if the scale be moved a little towards the left, so that the first of the set of these four lines be made to coincide with 4959 on the scale, most of the other lines in Lecoq de Boisbaudran's list may be picked out.

FOURTH SPECTRUM. *Iron and Selenium Spark.*—This spectrum is introduced to show the iron lines in spark. Two small pieces of Selenium were placed in the steel clips. When the spark passed, in lieu of striking from pole to pole, it flew with a long and bright flash across the surface of the selenium melting it in its way.

On examining the spectrum, it was found a combined one of air, selenium, and iron, some of the lines of the latter projecting in a most marked manner beyond the edges of the spectrum. These lines were evidently due to the clips. We tried Selenium two or three times, and always with the same result as to behaviour of the spark.

Now and then it seemed to cross between the poles, but ordinarily it preferred the longer route across the surface.

The Spectrum of Selenium will be found referred to in its order further on.

PLATE X.

First Spectrum. *Meteoric Iron Arc.*

Second Spectrum. *Meteorite Arc.*

Three specimens purchased of Mr. James R. Gregory were used in the arc:—

No. 1. Meteoric Iron. Atacanna 1827.

No. 2. Meteoric Iron. Tolucca 1784.

No. 3. Piece of Meteorite. Ausson 1858.

They all burnt with much scintillation in the carbon cup. The spectrum of No. 1 when examined was found identical in all respects with the spectrum of Iron in arc (third spectrum, last plate) and might have been taken for the same photograph.

No. 2 and No. 3 (the plates which are printed) also gave spectra evidently of iron, but differing from the spectra of No. 1 and of Iron in arc in last plate and from each other. Each of them is characterised by the large number of sharp and fine lines, which more especially in the case of the meteorite, intermediately fill up and occupy nearly the whole spectrum. Some of these lines it is true may be traced very faintly in our spectrum of Iron on Plate IX., but they appear to come out relatively stronger and brighter in our present plates. Meteorite seems also to differ from meteoric Iron in the greater length of spectrum (note group of fine lines to the extreme left), and in the greater number of its fine lines generally. This will be particularly noticed about the brighter and wider part of

the spectrum where the coarse and strong lines mainly prevail. Some of these, which have dark intervals in the case of meteoric Iron, are connected by and filled up with fine lines in the case of meteorite. Note also a thick double line about 4048 in meteorite, which is doubtfully represented in the meteoric Iron spectrum.

THIRD SPECTRUM. *Lead Arc.*—Piece of metal in carbon cup. Arc moderate.

FOURTH SPECTRUM. *Lead and Antimony Spark.*—Small lump of antimony in one clip; small bar of lead in the other. Current reversed at half exposure. Lecoq de Boisbaudran gives [PLATE XXIII., Plomb métallique Etincelle] lines at 5044, 5003, 4386, 4245, 4167, 4056, noting 4056 as very characteristic. Lines appear in our arc spectrum corresponding with his 5003, 4386 (4245 and 4167 are mixed up with the point lines) and very prominently indeed 4056. We have lines also about 4825, 4750, and 4700, which he does not give. In the spark spectra we get prominently Boisbaudran's 5044, a bright line about 4780, a tremendous one at 4400, another still larger at 4250 (Boisbaudran's 4245?), and lastly 4056, very sharp and well defined.

The wonderful inflation and flare of the two lines at 4400 and 4250 are to be noted. In the case of the latter line the flare appears unequally towards the violet side. Other smaller lines are in the spectrum (see Magnesium and Lead, second spectrum on next plate).

The Antimony Spectrum has been already described, but note the glare of light and thickening of the lines before referred to in reference to that spectrum.

PLATE XI.

First Spectrum. *Lead and Magnesium Spark.*—Small bar of Lead in clip; Magnesium ribbon cut to a point in other clip. Current reversed at half time.

Second Spectrum. Same as above, except that the metals are reversed in position. A condensing lens was used in front of slit.

Third Spectrum. *Magnesium Spark.*—A piece of magnesium ribbon, cut to a point, used in each clip. Slit ·001 inch. Exposure fifteen minutes.

Fourth Spectrum. *Magnesium Arc.*—Piece of ribbon coiled up in the carbon cup, quickly ignited, and long arc obtained; much oxide formed.

Lecoq de Boisbaudran gives [Plate XII. Chlorure de Magnesium] lines as follows: group, 5183, 5172, 5167, very bright (*b* in solar spectrum), then a band of rays, commencing with 5006 and ending with 4958, and then single lines, 4705 and 4483.

Our first two spark spectra are mainly conspicuous for the great blaze of light at about 4500. This is very marked and characteristic, and extends in each case considerably beyond the margin of the spectrum. In our third spectrum (Magnesium ribbon in each clip) the print is cut off in vertical by the limited width of mask; but upon examining the original plate the glare

of light on the lower margin of the spectrum at 4500 is distinctly traced to extend beyond the margin of the spectrum to a length equal to the glare itself (nearly half the width of the spectrum) as a single line terminating in a minute knob or inflation (limit of prism surface?). Two bright lines at about 4725 (Boisbaudran's 4705?) and 4360 are also seen to project beyond the spectrum, though not to so great an extent. Both of these last lines appear to be repeated in the arc spectrum, while the large 4500 is missing there. The group *b* in solar spectrum is seen in both spark and arc spectra as a double line only (tested by this, our Scale is a little too much extended towards the extreme left). Then in the arc comes the band of lines at 5006, then 4725 and 4360, and lastly two bright lines at about 4245 and 4180. The other and fainter lines in the arc seem due to carbon.

PLATE XII.

First Spectrum. *Manganese Arc.*—Powder metal in the carbon cup; arc moderate, with some scintillation, taken with battery of 30 Grove cells.

Second Spectrum. Same, but taken with battery of forty Grove cells. Lecoq de Boisbaudran's Plate XVII., Chlorure de Manganese en solution, Etincelle courte, is found closely to compare with our spectrum in principal lines, and the two spectra were selected to form a scale by comparison and interpolation as described in the Introduction. The lines given by

Boisbaudran are 4825, 4784, 4766, 4755, 4738, 4727, 4710, 4502, 4462, 4437, 4415, 4282, 4266, 4260, 4237, 4084, 4063, 4047, 4039. These were also compared with Dr. Watts' list of (Huggins') lines of Manganese; and then those most easily recognised with corresponding ones in our spectrum were used as materials for the Scale. The principal lines are easily sorted out by the aid of the upper spectrum.

THIRD SPECTRUM. *Mercury Spark.*—Globule of the metal in a small glass cup with Platinum communication passing through the bottom of the cup. Platinum wire electrode above. Exposure twenty minutes. Spark brilliant and rapid.

The spectrum is characterised by the misty and indistinct appearance of the air lines. They are, however, sufficiently defined to indicate position of the metal lines, these last being coarse and thickened. Lecoq de Boisbaudran gives [PLATE XXV., Bichlorure de Mercure] a strong line at 4357, and two other lines at 4078 (faint), and 4047 : 4357 is well marked in our spectrum, also 4047, and there is an additional strong line at the end of the spectrum about 3985.

FOURTH SPECTRUM. *Molybdenum Arc.*—Powder metal in carbon cup. Soon formed a bead, which remained quiet at bottom of the cup. Arc long, and gave a bright lambent glow rather than a brilliant stream.

Dr. Watts gives lines (Thalén), 4979, 4867, 4829, 4818, 4757, 4730, 4706, 4536, 4475, 4433, 4411, 4380, 4326, 4277.

The group 4737, 4730 and 4706, is easily distinguished, and other of the foregoing lines may be picked out in the clearer parts of the spectrum.

PLATE XIII.

First Spectrum. *Nickel Arc.*—Small pieces of metal in the carbon cup, arc short, spectrum tolerably clear of point lines. Lecoq de Boisbaudran gives [Plate XIX., Chlorure de Nickel] a long list of lines commencing with a strong one 4984, and ending at 4288, and with characteristic ones at 4715 and 4401.

4715, 4647, 4606, 4550, 4461, and 4401 (strong), may be picked out in the clearer part of our spectrum towards the red end. Notice also a sharp bright line in a clear space about 4000.

A small bottle without a label containing a powder was found in our cabinet. The spectrum when photographed was at once easily identified with our present plate.

Second Spectrum. *Niobium Arc.*—Powder metal in carbon cup, arc moderate. Dr. Watts quotes Thalén as stating that the lines of Niobium are too faint to be measured satisfactorily.

Our spectrum, however, after excluding the carbon lines has a considerable set of bright ones which must belong to the metal. These may be seen at about 4861 (F), 4615, 4590 (strong double), two bright lines with a fine one between them about 4435 and 4405, a set of three lines, (a single and then a double) about

4260, a bright one with shading towards the violet, at 4100 (*h*), (it is curious that F and *h* places of hydrogen lines should each have prominent lines falling in the same or very closely approximate positions in this spectrum), a thickened or double line about 4050 (position also of a carbon line), and a double one near to the last about 4040.

THIRD SPECTRUM. *Palladium Arc.*—Piece of metal in the carbon cup, arc moderate, spectrum showing carbon lines indistinctly.

Lecoq de Boisbaudran gives [PLATE XXVII., Chlorure de Palladium,] a set of lines at 5118, 5114, and 5111, then single lines at 5063, 4969, and 4917, then three well-marked lines at 4874, 4818, and 4788, then one at 4475, then a strong one at 4214, concluding with two at 4170 and 4088. The lines at 5111 and 5063, and the stronger ones at 4874, 4818, 4788, 4475, and 4088, may be all picked out from our spectrum. A carbon line between H^1 and H^2, seems also to have another by its side not belonging to it. Note also extension of spectrum towards the violet, as in the cases of Iridium and Ruthenium.

FOURTH SPECTRUM. *Platinum Arc.*—Small roll of foil in the carbon cup, arc short, spectrum poor, mainly carbon lines. Lecoq de Boisbaudran gives [PLATE XXVII., Chlorure de Platine] a set of lines comprising (with others) 4554, 4524, 4501, 4415, 4390, 4118. These seem distinguishable in our spectrum, and there are also two bright lines about 4250, not given by Boisbaudran.

PLATE XIV.

First Spectrum. *Rhodium Arc.*—Piece of metal in the carbon cup. Spectrum of even character, with many sharp metal lines. Point lines not prominent, except in the centre of the spectrum,

Here again Dr. Watts quotes Thalén, that the lines are too faint to measure, but many may be picked out from our print. Note especially two sharp lines between 5000 and 4950, a double line near F, a line about 4590 near two point lines, another about 4420, with two fine ones towards the red, and a strong one near a carbon line about 4400. Other lines will also be found, intermediate of the point lines, in the region extending from 4400 towards the red end of the spectrum. Note also a set of three lines (strongest towards the red), about 4265, and a strong set of three lines of equal intensity, the centre one about 4125. N.B. In this and other cases in which no authentic list of lines is referred to, it is useful to test the spectrum by the carbon points ruled out, Plate V., so as to eliminate the point lines from the spectrum.

Second Spectrum. *Ruthenium Arc.*—Piece of metal in the carbon cup, arc short. This spectrum has already been referred to under the head of 'Iridium.'

Third Spectrum. *Selenium and Tellurium.*—Small piece of these in each clip, current reversed at half.

Fourth Spectrum. *Selenium and Aluminium.*—Small piece of Selenium in one clip, Aluminium

wire in the other, current not reversed. The Aluminium spectrum, Plate II., has been described *ante*, p. 19. It is, however, from the absence of air lines, well shown in the present print. See also Plate XVII, Second Spectrum, Titanium and Aluminium. The spark passed more freely than when both electrodes were of Selenium, but still played over the surface of the Selenium partly fusing it. (Compare Iron and Selenium Spark, Plate IX., and note the Iron lines in each of the present spectra as affecting the Selenium pole of the spectrum).

In the third spectrum the Selenium has partly melted away, and the spectrum is doubled.

The spectrum of Selenium is distinguished by its quantity of very fine sharp lines towards the red running into bands towards the violet. Many of these lines in our plates are too fine to print satisfactorily. The lines are best seen in the spectrum Iron and Selenium, Plate IX., the bands in our two present plates.

In each case the metal lines and bands follow the ordinary rule of being found at the edges of the spectrum. There is an inclination to mistiness or glare at the poles, as in the case of Antimony. Dr. Watts gives from Plücker a long list of close lines towards the red end, and of bands towards the violet end of the spectrum.

We pick out conspicuously in our spectrum bright lines at about 5000 (Plücker's 4994 ?), 4850 (Plücker's 4845 and 4840 ?), 4880 (Plücker's 4776 ?), 4600 (Plücker's 4606 ?), and 4425. The bands towards the

violet are also well seen about 4225, 4190, and 4140. The two sharp lines about 4015 and 3998 are Iron lines.

PLATE XV.

First Spectrum. *Silver Spark.*—Small bars of the metal in clips. Spark short and white, edged with greenish glare. Exposure twenty minutes.

Second Spectrum. *Silver Arc.*—Piece cut from bar of the metal in the carbon cup. Soon became red hot, and melted into a bead, which rotated in the cup, and from which the arc sprang. Arc moderate, and tinged with green.

Lecoq de Boisbaudran gives [Plate XXV., Azotate d'Argent en solution] a set of lines commencing with two very strong ones at 5464 and 5208, a band or set of lines at 5022, 4997, 4968, and following on with 4669, 4622, 4570, 4518, 4475, 4434, 4396, 4208.

In our spark spectrum we have in our plate a line about 5150, which has not printed. 4997 seems indicated by the breadth and strength of the 'spark' line. Four air lines, 4960 to 4900, are unusually strong. 4669 is marked by projecting slightly beyond the spectrum. The other lines do not show. The battery and coil power does not seem to have been sufficient to bring out the metal lines satisfactorily. In our arc spectrum we find brilliant lines corresponding with 5208 (our Scale, as we have noticed before, is a little too much extended towards the red in this part of it),

4690 (Boisbaudran's 4669?), 4480 (his 4475?), and two very strong lines, about 4215 (place of a point line), and 4050.

THIRD SPECTRUM. *Silver and Copper Arc.*—A small piece of metal wire in the carbon cup. This was procured from a jeweller, and warranted pure as being the silver wire employed by the natives of India in making filagree and other ornamental work. It had, however, I thought, a slightly reddish tint, and upon combustion (behaving much the same as the last specimen) the spectrum proved a mixed one of copper and silver.

For some reason which we do not trace, the spectral image is smaller in size than that of Silver arc. The enlargements are both once, and the difference is in the original plates. It is however almost exactly the same size as Copper arc, first spectrum, PLATE VII.; and this last can be used to distinguish the copper lines in our present spectrum. They mainly usurp the spectrum, but the Silver line at 5208 (apparently doubling the copper line 5218), and those at 4215 and 4050, are easily recognised.

FOURTH SPECTRUM. *Solar Spectrum.*—This spectrum was photographed mainly for the purpose of comparison with the metal spectra in regard to the dispersion of the spectroscope, but also as a sort of check upon our Scale, see PLATE XXI., Scale and Solar Spectrum. The solar lines are fairly seen, but they are too fine and close together, and on too small a scale to make them available for comparison with the coarser

metal lines. Indeed, this comparison did not form part of our intended work. The photograph was taken on a fine, but not absolutely clear, day in winter with the sun near the meridian. A table was arranged in the open air, facing the south, with the spectroscope and camera as used for the metals upon it, the photographer's back being to the sun. The slit was made as fine as possible, and a plane mirror and condensing lens were used to throw the sun's image in a parallel direction upon it. The slit was covered with a cap, which was removed when it was desired to take the photograph. Of the two successful plates, one was exposed three seconds, the other two seconds. The last has the lines sharpest and most distinct. This plate indeed is very sharp, and the lines are well defined; but it is difficult to get as good an effect in the prints.

The lines in the plate are seen nearly as far towards the red as *b*. In the print they stop short midway between *b* and 'Spark.' F, G, and *h* are well marked. The print stops short at H^1; but in the plate a bright space with four dark lines succeeding H^1 is seen, and then the spectrum terminates abruptly with the dark interval representing H^2.

PLATE XVI.

First Spectrum. *Strontium Spark.*—Pieces of metal in the clips. Spark bright, metal melted rapidly. Spectrum (like Barium) characterised by the absence of

air lines, and by the broad fuzzy character of the metal lines. Lecoq de Boisbaudran gives [PLATE IX., Chlorure de Strontium en solution] four lines (second and fourth the strongest) with places as follows:— 4307, 4215, 4163, 4079.

Assuming the first expanded line to be 4307, and placing the Scale accordingly, the other three lines 4215, 4163, 4079, towards the violet, fall into their proper places. The bright unexpanded line towards the left of 4307 seems to be an air line.

SECOND SPECTRUM. *Tellurium Spark*, (see also PLATE XIV., Selenium and Tellurium Spark).—Rough pieces in each of the clips, which wore away quickly, the spark occasionally running to the clips. Spectrum characterised by comparative absence of air lines and a general likeness to Selenium without its very sharp lines. Dr. Watts gives lines (Thalén) 4895, from his own observation 4866, 4832, 4785, then three (Huggins') 4709, 4664, 4652, then one of his own 4602, and then (Huggins') 4599, 4544, 4479, 4352, 4302, 4259, 4063. In our Spectrum, lines or bands are well traced between 4900 and 4650 in places nearly corresponding with some of the above, as also a band at about 4485 (4479 ?) and some bright bands in the margins of the lighted-up region 4350 to 4225.

The line or band 4063 seems also recognisable on the lower margin of the spectrum.

THIRD SPECTRUM. *Thallium and Indium Spark* (for Indium Arc, see Second Spectrum, PLATE VIII.)

—Small pieces of the metal in the clip, current reversed at half, spark bright. Spectrum characterised by absence of air lines, and distinctness of metal lines. On the print, seven lines belonging to Thallium may be counted. Two if not more, finer ones appear on the plate. Seven lines at least are seen on the Indium margin of the spectrum, including the large ones seen in the Arc Spectrum of Indium which, as in the case of the arc, are very sharp and well defined and run nearly across the spectrum. (This spectrum was originally a short image, and is also very slightly underenlarged so that the whole is slightly shorter than the Indium Arc Spectrum. Allowance must be made for this in placing the Scale.)

Lecoq de Boisbaudran gives no lines for Thallium in our part of the spectrum, and only the two referred to *ante* for Indium. Dr. Watts gives for Thallium, on his own, Huggins', and Thalén's authority lines at 5153, 5085, 5078, 5054, 4980, 4945, 4893, 4767, 4737, 4112. Our Scale indicates on our spectrum lines which correspond with 5153 (scale too much extended in that part), 5078, and notably 4767 (very bright and broad). A line is shown about 4300, and one about 4120 (4112?) is faintly indicated. Two lines appear in the plate about 4945 and 4893 which do not show in the print. Dr. Watts gives for Indium (Thalén) 5532, 4509, 4101. Allowing for the difference in size of the image before referred to, 4509 and 4101 are easily distinguished sharp and well defined and projecting beyond the spectrum; 4532 is not definitely traced,

but on each side of 4700 broad and bright lines or bands are seen. Note also a bright line about 4090, with a faint one beyond. A slight flare seems to run along the Indium margin of the spectrum.

Fourth Spectrum. *Thallium Arc.*—Piece of the metal in the carbon cup. Arc moderate, metal very soon volatilised, and we doubted whether any trace of it was impressed upon the spectrum. A fine line at the extreme red end of the spectrum about 5250, and others about 4610, 4405, 4260, and 4100, are however intermediate of the point lines ruled out. They may be metal lines, but their character is not what one would expect in that case.

PLATE XVII.

First Spectrum. *Titanium Spark.*—Two pieces of ore in the clips. Spark occasionally gave a reddish flare.

Second Spectrum. *Titanium, Aluminium, and Palladium.*—Palladium in clip, for upper pole. Lower pole a small Aluminium cup, (with Platinum wire let through the bottom) filled with Titanium in powder. Current reversed half time. Spark long and bright, and occasionally played round edge of the cup, from which some of the powder was from time to time ejected. Aluminium spectrum due to the cup very apparent on upper edge of spectrum in print. Air lines in first spectrum weak towards the red end.

Third Spectrum. *Titanium Arc.*—Metal powder

in the carbon cup. Soon formed a bead, which remained quiet in the cup. Arc long and lambent.

Dr. Watts gives (with wave lengths by Thalén) a long list of Titanium lines, most of them of considerable intensity, and in some parts of the spectrum very closely packed together. Between 5300 and 4163 we count no fewer than 149, the greater number being of the higher range in intensity.

Our spectrum contains several groups of fine lines close together. One to the extreme left at about 5025 to 4975. A wider set, about 4925 to 4850; another wide set, 4700 to 4625. A set of fine bright lines 4560 to 4525, and another set about 4390 to 4340. Single bright lines are distinguished about 4775, 4550, 4460. A set of five of about equal distance apart between 4450 and 4400, and a single one about 4300. The single ones may be Thalén's 4779, 4549, 4468, and 4299, the first being of Watts' intensity 6 and the three last his intensity 10. Going back to the spark spectra, we fail to trace much evidence of the metal lines. In the first spectrum the principal evidence of the metal is confined to a few sharp faint lines partly crossing the spectrum. 4549 is thus seen, and two others about 4420.

The strong well-defined lines in the bright part of the Spectrum are Iron (hence the red flare in the spark). In the second Spark Spectrum no more is seen, the strong lines on the upper margin being those of Aluminium.

Dr. Watts gives lines for *Palladium* (Huggins and

Thalén) 5062, 4876, 4818, 4787, 4474, 4278, 4212. In our spectrum 4876 is indistinctly traced, then a line thickened at margin about 4710, 4474 seems well marked. About 4300 is a conspicuous bright line projecting beyond the spectrum (4278?) with others near it. A bright line is well seen at 4225 (4212?) and another not so bright at about 4165. A faint line is also seen beyond H^1, which may belong to the metal.

FOURTH SPECTRUM. *Tin Arc.*—Some granular metal in the carbon cup. Arc short, spectrum conspicuous for a few metal lines and the brightness of the lines in the region of H^1 and H^2. All the other point lines (except 4225) indistinct. Lecoq de Boisbaudran gives only one line in our part of the spectrum which is easily recognised, 4526; but note also a line about 4100, which does not seem to be a point line, and which has the peculiarity of only partly crossing the spectrum.

PLATE XVIII.

FIRST SPECTRUM. *Tin and Zinc Spark.*—Small Zinc bar in one clip. Granular tin same as used in arc in small glass cup, with platinum wire connection for other electrode, current reversed at half, slit rather wide.

SECOND SPECTRUM. *Tin and Zinc Spark.*—Second plate of same.

Dr. Watts gives for Tin (Thalén) 5100, 5021, 4923, 4858, 4585, 4524, (Boisbaudran's 4526). The First Spectrum shows towards the red end 5100 and

4923. Then referring to the second spectrum, we get 4858, 4605 (4585?), 4550, 4540, and about 4515 (4524?). The one bright line in the arc (4524) is but faintly represented in the spark spectrum.

THIRD SPECTRUM. *Uranium Arc.*—Powder metal in the carbon cup. Arc moderate, some scintillation. Spectrum much glared, with many indistinct rather coarse lines, from among which the point lines about H^1 and H^2 and 4225 shine out conspicuously. Dr. Watts gives a set of lines (Thalén), among which 4472, 4393, 4374, 4362, and 4340, may perhaps be selected in our spectrum.

FOURTH SPECTRUM. *Vanadium Arc.*—Powder metal in carbon cup. Arc moderate. A splendid spectrum, characterised by a family likeness to Titanium, but with a yet greater quantity of bands of close sharp lines. Dr. Watts gives a list (Thalén) of thirty-two lines between 4881 and 4085 (about where our spectrum begins and ends). Groups of lines are found with centres about 4843, 4585, 4389, and faint lines extending from 4130 to 4085. This will be seen to very closely agree with our spectrum, in which the groups quoted (with others) stand out very beautifully.

PLATE XIX.

FIRST SPECTRUM. *Wolfram Arc.*—Powder metal in carbon cup. Arc moderate. Spectrum somewhat like Uranium in character, but with brighter lines and longer.

Dr. Watts gives lines (Thalén) for Tungsten 5014, 5007, 4981, 4887, 4842, 4680, 4660, 4659, 4302, 4295, 4269. Most of these may be recognised in our spectrum.

Second Spectrum. *Yttrium Arc.*—Powder metal in carbon cup. Spectrum well defined, point lines absent, notably those about H^1 and H^2 and others generally seen towards the violet. Yttrium and Erbium are given as a combined spectrum by Dr. Watts, but our photographed spectra have little in common.

Dr. Watts gives in our part of the spectrum, 4822; then two we do not find; and then 4674, 4643, 4505, 4422, 4397, 4374, 4357, 4309, 4236, 4227, 4176, 4167, 4142, 4127, 4102. 4102 is very well marked, and if the Scale be adjusted to this line, many of the others may be picked out.

Third Spectrum. *Brass Arc.*—Two pieces of stout brass wire. Arc did not form well. A mixed spectrum of Zinc and Copper, the principal lines of each metal being easily distinguished, the zinc lines towards the red end of the spectrum, the copper towards the violet end.

Fourth Spectrum. *Brass Spark.*—Two points of brass wire as electrodes. Spark passed freely, spectrum deficient towards the violet, introduced to show the double zinc line about 4925.

PLATE XX.

First Spectrum. *Zinc Arc.*—Small piece of the metal in carbon cup. Arc brilliant. Much oxide formed. Lecoq de Boisbaudran gives [Plate XX., Chlorure de Zinc en solution] three brilliant lines 4812, 4721, 4681, and another not so strong at 4630. Dr. Watts gives (Huggins') faint lines at 5049 and 4970, two strong ones at 4924 and 4911, a faint one at 4867, and then three strong ones at 4809, 4722, 4679, (Boisbaudran's 4812, 4721, and 4681). Compare the arc spectrum, the two tin and zinc spark spectra on Plate XVIII. and the brass spark spectrum on Plate XIX.

Boisbaudran's 4812, 4721, 4681, and 4630, are all very prominent in the arc spectrum, together with a double one at the other end of the spectrum, about 4060, (sed quære a point line. It or a line very approximate occurs in other arc spectra). In the tin and zinc spark spectrum No. 1, 5049, 4924, and 4911, and 4809, 4722, and 4681 are seen without 4630.

In tin and zinc spark No. 2 the three stronger lines alone are seen, while in brass spark 4924 and 4911 alone appear.

Such effects are probably due in the case of a single metal to difference in strength, and temperature of spark or arc; but in the case of mixed metals the effects produced, and the causes leading to them, seem to have a complication of their own.

Second Spectrum. *Zirconium Arc.*—Thin flakes of the metal in carbon cup. Arc short and brilliant, thick coat of oxide formed, occasionally stopping the current and requiring pole to be cleaned; slit fine. Spectrum characterised by three prominent shaded sets of bands or lines towards the red end. Dr. Watts gives (Thalén) five strong lines (intensity 10) at 4815, 4771, 4738, 4709, 4686, then follow (intensity 4) 4497, 4494, 4443, 4380, 4370, 4360, 4242, 4241, 4228, 4210, 4209, and lastly (intensity 8) 4155, 4149.

The five strong lines 4815 to 4686 are easily distinguished in our spectrum; and 4155, 4149, may be picked out in the brighter part of the spectrum. There also appear metal lines beyond; until, at the extreme violet end of the spectrum; we find two intense lines, one midway between H^1 and H^2, and the other a little beyond H^2.

Third Spectrum. *Zirconium and Palladium Spark.*—Small pieces of the metal in clips. Many indications of sharp metal lines on the upper (Zirconium) margin of spectrum about 4686, 4575, 4550, 4540, 4530, 4380, 4370, 4228, and 4155, (the last two rather strong), and in other places. A line (two are seen in the original plate), appears also in this and the next spectrum at the extremity of the violet end, which probably corresponds with the intense one in the arc. Palladium margin weak, and lines not easily distinguished.

Fourth Spectrum. *Zirconium Spark.*—Small flakes of the metal in the clips. Spectrum confined to

centre, dark strong lines corresponding to 4228, and 4155 in last spectrum well seen. Three lines (Iron ?) project from the upper margin of last spectrum in the region about G, which may be also identified in this spectrum. Note also line at extreme violet end.

PLATE XXI.

Scale and Solar Spectrum.—Both have been previously referred to and described.

N.B. Potassium and Sodium were tried in arc and spark, but caught fire and would not last long enough to give an image. Cæsium alum was tried (moistened in glass cup) with spark, but gave no result. Silicon in arc, the upper pole was quickly covered with a white crust of oxide which stopped the arc current. Tantalum in arc gave only point lines.

THE GASES.

Some of the gases have been added by way of supplement to the arc and spark spectra. The set of the gas photographs is by no means complete; and they are rather experimental than otherwise, as three different instruments have been used for their production, and the one which gave the best results came last in the field. The spectroscopes employed have been already described in the Introduction; and are there and in the following notes distinguished respectively as A, B and C. As the dispersion (to preserve light) was

necessarily small, and as the gases give each a whole and complete spectrum due to itself, it has not been considered necessary to adapt a scale to the photographs. Some of the gases are compared, the one with the other; and others are compared with hydrogen, or show one or more of the hydrogen lines: and in this way a general idea is in most cases obtained of the position of the principal lines or bands in the spectrum without reference to scale. Of course individual aspect is still more marked in the case of the gas spectra than in the more complicated spark and arc spectra of the metals. The remarks appended to the gas spectra will mainly consist of notes as to the behaviour of the tubes and brief indications of any special features in the spectrum.

PLATE XXII.

NITROGEN.

FIRST PRINT. *Line Spectrum of Nitrogen.*

THIRD PRINT. *Band Spectrum of Nitrogen.*

CENTRE PRINT. *Line and Band Spectra of Nitrogen compared.*

The first photograph (line only) was taken with spectroscope A. The centre and third with spectroscope C. Two nitrogen tubes were employed, the one with coarse capillary part for the line spectra, the other with fine capillary for the band spectra.

The spectra were easily taken with twelve to fifteen minutes exposure, and the small coil was generally enough to work a single tube. To procure the line

spectra, the condenser (with two plates only) was introduced into the circuit. The nitrogen line first spectrum is remarkable for its brightness towards the red end, but with a falling off in light towards the violet. This feature seems characteristic of the line spectra in general. The line spectrum in the centre print is weak and poor in lines as compared with the first line spectrum, partly perhaps for want of illumination in the tube, but mainly that being the side tube, (the band tube was in front of the slit) the image was weakened by reflection from the comparison prism used to obtain the second spectrum.

A fine line is noticed on the extreme left of the band spectrum (centre print), which is attributed to F hydrogen, and serves to mark the position of the nitrogen bands. Twenty of these are counted in the lower band spectrum.

PLATE XXIII.

NITROGEN (continued).

First Print. *Nitrogen Line and Band Spectra compared.*

Second Print. *Nitrogen Band.*

Third Print. *Nitrogen Band and Hydrogen compared.*

Fourth Print. *Nitrogen Capillary part of Tube and Nitrogen Bulb part of Tube*, (near red pole, as distinguished from violet pole on next plate), *compared.*

All these were taken with the spectroscope B (quartz), and are on the smaller scale. In the nitrogen

line and band compared spectrum, the band tube was in front of the slit and the line tube at the side. In the hydrogen and nitrogen compared spectra the hydrogen tube was in front, and the nitrogen at the side; and unless the contrary is stated, it holds good throughout as to all the compared spectra, that the tube at the side is the upper spectrum and the tube in front of the slit is the lower spectrum in the resulting plate.

As might be expected, the spectral images in the case of the quartz spectroscope lose somewhat towards the red end of the spectrum, but gain much in the direction of the violet. About as many of the nitrogen bands are counted as in the last plate, but they are not the same. They commence at the bright edge of the band spectrum in centre print of last plate, and extend considerably further into the violet. An examination of hydrogen and nitrogen compared spectra (third print) will illustrate this. The faint line to the extreme left is F hydrogen. The bright line meeting the edge of the upper spectrum is near–G, the next is *h*, and then two other fainter lines of hydrogen.

PLATE XXIV.

NITROGEN (continued).

First Print. *Nitrogen Band (Capillary) compared with Nitrogen Violet Pole.* Spectroscope C.

Second Print. Same, but reversed in position. Spectroscope B.

Third Print. *Violet Pole.*—Spectroscope B.

In the first (large) print the nitrogen capillary

bands, probably from the tube not being well adjusted in front of the comparison prism, appear like lines. This is, however, not without advantage, as they thus indicate more clearly their position in regard to the violet pole lines and bands. F hydrogen may be seen as a faint line to the left of the violet pole spectrum in this print. The following wave lengths, as given by Dr. Vogel, may be interesting for comparison :—

Capillary part of Tube.	*Violet Pole.*
5066 bright.	5147 faint.
4975 "	5002 bright.
4913 "	4912 "
4862 very faint.	—
4811 bright.	4808 very faint.
4721 "	4704 very intense.
4666 faint.	—
4644 bright.	4646 very faint.
4570 very bright.	4569 bright.
4487 bright.	4486 "
4417 "	4417 very faint.
4363 "	—
4357 "	—
4345 "	4346 bright.
4273 "	4273 very bright.

Our lines extend considerably more into the violet. The violet pole has attracted considerable attention in connection with the Spectrum of the Aurora, mainly o account of the late Prof. Ångström's opinion, that 'the 'feeble bands of the Aurora spectrum belong to the spec-'trum of the negative pole, possibly changed more or 'less by additions from the banded or the line air 'spectrum.'

I have discussed this question at length in a paper, on the Aurora Spectrum, published in the 'Philosophical Magazine' for April 1875; and I only refer to it now to point out that the difficulty of actual line comparison which then existed might perhaps now be conquered.

With one or other of the instruments we have used, there really seems no reason why a photographic image of the more refrangible rays of the Aurora Spectrum should not be obtained without difficulty. I saw at Kyle Akin in Skye in September 1874, a fine double arc Aurora of great brilliancy which lighted up the whole landscape, and strongly impressed me with the idea that if proper apparatus had been at hand something in that direction might have been accomplished. Auroræ have unfortunately been quite quiescent lately. Should this state of things alter, the experiment would be well worth trying. As much as possible, say two thirds, of a long slit should be given to the Aurora, and the remaining one third kept in reserve for a comparison spectrum. Dry plates might be used and a considerable amount of exposure given. The Camera should be directly pointed to the brightest part of the Aurora. After exposure and before disturbing the apparatus, the two thirds of the slit used for the Aurora should be covered, and the remaining third which was covered during exposure should be employed for the projection of a tube or solar spectrum on the same plate.

If a tube spectrum only were desired for comparison,

a prism might be used on the slit in the usual way, but I prefer a direct image when practicable.

To obtain absolute measurements of the lines a double slit (the upper half moveable by a micrometer screw) like one I have deposited at South Kensington, might be employed. Two photographic images being taken, one under the other, the lines are measured by the relative position of the same lines in the two images being compared with the ascertained value of the micrometer movement.

PLATE XXV.

NITROGEN (continued).

First Print. *Band Spectrum of Nitrogen (Capillary) with Magnet.*

Second Print. *Band Spectrum of Nitrogen (Capillary) without Magnet.*

The Electro-magnetic experiments leading to these plates have been fully detailed in the Introduction: Spectroscope B (quartz) was used for them. The plate with magnet is brighter, especially towards the violet.

Centre Print. *Ammonia* (NH_3) *Tube*, capillary part fine, tube lighted up easily. A nitrogen spectrum is alone prominent.

Fourth Print. *Line Spectrum of Nitrogen Tube, and Spark in Air compared.*—This print is from the original without enlargement, and does not show so much as the plate. The line tube spectrum was obtained by use of the Condenser in the usual manner. The spark

passed between two platinum points introduced into the circuit. The stronger lines correspond in position.

Fifth Print, is introduced into the plate in connection with the second spectrum (Spark in Coal Gas) on Plate XXVII.

The upper spectrum is that of spark in air as taken between Platinum points. The lower is spark in coal gas (after referred to) and the combined spectra are printed to illustrate the approximate position of the lines in the spectrum of spark in coal gas at ordinary pressure as compared with spark in air. Spectroscope C was used. Image not very good, but better on plate than in the print. It would not bear enlargement with any advantage.

PLATE XXVI.

HYDROGEN.

First Print. *Hydrogen Tube.*—Small in capillary part, lighted up well with small coil. A portion of the capillary bore, comprising the whole circumference of the tube is decomposed, and has the appearance of being obscured by a yellow white coating. The bright red tint of the discharge was lost here, and the lines of the spectrum were partly extinguished in a white misty haze. This effect is seen in the print.

The spectrum, as to principal lines, will be seen to consist of—

No. 1. F. 4861.
2. Near–G, 4340 (G 4307).
3. *h* 4101.
4. A sharp bright line, not quite as distant from *h* as *h* is from G.
5. A line faintly seen in the print beyond No. 4, not quite as distant from No. 4, as No. 4 is from *h*.

No. 5, in the original plate, is fairly strong, and close to, and on each side of it, are also seen two single fine lines, the one on the violet side being rather the more distant (see also Centre Print, Plate XXVIII.).

Lines of some breadth and intensity are to be remarked between the more prominent lines before described. Two short ones between No. 1 and No. 2 (five are counted on the plate), three or more between No. 2 and No. 3, and three between No. 4 and No. 5. The spectrum is also filled with a number of very fine and sharp lines, traces of which are indicated in the print. Whether these intermediate lines are due to hydrogen or to tube impurity is not clear; but as some of the coarser ones are traced in the second spectrum on next plate, (Spark in Coal Gas), it is probable that these at least are due to the gas.

Second Print. *Spark in Coal Gas.*—This spectrum and the way it was obtained have been already described in connection with the Carbon Spectra. Another but less bright print is found on Plate VI.

This spectrum is on the same scale as the arc and spark spectra, and therefore larger than our Gas

spectra in general. The original, before enlargement is found on PLATE XXXIII. The print is here introduced to illustrate the expansion of a hydrogen line. Note traces of a narrow dark space dividing the centre of the expanded line. The sharp lines are attributed to Carbon.

THIRD PRINT. *Hydrogen Tube*, taken with spectroscope B, wide slit. Lines 1, 2, 3, 4, and 5, in last spectrum are brightly seen, (No. 5 very bright), a sixth is easily traced some distance beyond, and a seventh faintly indicated where the continuous spectrum ends.

PLATE XXVII.

HYDROGEN (continued).

FIRST PRINT, Compared spectrum. *Spark in Air between Platinum Points, and Hydrogen Tube.*—Spectroscope C. Large coil and condenser used for spark. Small coil for the tube. Exposure for tube 15 minutes, for spark 5.

The spark spectrum is seen to extend far into the violet; considerably beyond the spark in air, as taken in combination with the metals. The four principal hydrogen lines, commencing with F, are well seen, some intermediate ones faintly.

Near–G is the only hydrogen line that can be absolutely traced into and through the air spectrum.

SECOND PRINT. *Spark in Coal Gas at ordinary pressure.*—The manner in which this spectrum was obtained has been described under the head of Carbon

among the Arc and Spark Spectra, and the peculiar difference between this and the print, on Plate XXVI. (also spark in Coal Gas) has been noticed.

This spectrum should be compared with the first print in this plate, (Spark and Hydrogen) and with hydrogen on the last plate. The image is enlarged *very slightly* more than the other two spectra, but not enough to prevent easy comparison. Taking the principal lines of Hydrogen in their order,—

F is seen as a bold very bright expanded line.

Near–G is seen to the left of a well defined line not found in the ordinary hydrogen spectrum, as a still more expanded bright band or stripe with conical ends. A bright sharp line between F and near–G, surrounded by a nebulous halo coincides with one of two short lines in the hydrogen tube.

Beyond near–G, we have a blaze of continuous spectrum, crossed by four prominent lines.

The first of these lines has been already noticed, and does not appear in the hydrogen spectrum.

The second falls very close upon the place of *h* in the hydrogen tube.

The third does not appear in the hydrogen tube.

The fourth, and last, and the most expanded, falls close upon the place of No. 5 in the hydrogen spectrum.

Intermediate of Nos. 1 and 2, and of Nos. 2 and 3, are faintly but distinctly traced some of the less strong lines of the hydrogen tube. The general position of this spectrum as compared with air is indicated by the small print on Plate XXV. before described.

PLATE XXVIII.

OXYGEN.

First Print. *Band Spectrum of Oxygen*, tube No. 1, spectroscope C.

Second Print. *Band Spectrum of Oxygen*, tube No. 2, same spectroscope.

These two tubes were worked by the larger coil, with batteries purposely weak; exposure fifteen minutes. In the case of No. 1 tube the colour of the capillary stream was a pale pink. There was considerable stratification in the bulbs of both tubes.

The spectrum of No, 1 is a short bright one, composed of a mixture of oxygen and hydrogen lines, the latter probably due to moisture in the tube. F hydrogen is seen as a single line to the extreme left; near–G is seen very bright at the edge of the illuminated part of the spectrum. *h* is seen in the centre of the spectrum, apparently doubled by a strong oxygen line. The other less distinct lines or bands are those of oxygen. In the plate some finer lines are seen intermediate of the coarser ones. Professor Draper is said to have recently found some of the oxygen lines as bright ones in the solar spectrum.

The capillary stream of tube No. 2 was somewhat redder in tint. The spectrum was taken and enlarged as one of oxygen, to accompany that of No. 1; but a comparison with the upper print on Plate XXVI. will show that while the continuous spectrum and some

indistinct lines or bands are probably due to oxygen, the principal bright lines are those of hydrogen. It will be noticed, too, that the triple line mentioned as No. 5 and faintly seen in the hydrogen spectrum, shows in the spectrum now examining (to the extreme right) as a strong double line, with shading off towards the violet.

THIRD SPECTRUM. *Line Spectrum of Oxygen.*—This was obtained in the usual way, by introduction of the Condenser (with two plates) into the circuit. The spectroscope used was A.

Four line spectra are printed which have been taken with this instrument: Nitrogen, PLATE XXII.; the present (Oxygen); Carbonic Acid, PLATE XXX.; and Coal Gas, Plate XXXIII. Each of the three last spectra, though differing in other respects, has a marked character in common, viz. a bright line to the left, assumed to be F hydrogen, and a bright broad band of light more towards the centre with a sharp line close adjoining on the violet side. The other lines by their variation show that the spectra, as a whole, are not by any means identical; but these particulars seem constant. It might be expected that the bright line adjoining the band would be 'near–G' hydrogen, but this is not the case. An examination of the original plates shows that the enlargements are strictly correct, and that the broad band itself exactly occupies the place of 'near–G' in the hydrogen spectrum. It would seem that the images of spectroscope A give the line spectrum towards the red end, while those of spectro

scope B (quartz) give the line spectrum towards the violet (see PLATE XXIX. line oxygen).

PLATE XXIX.

OXYGEN (continued).

All the photographs on this plate were taken with spectroscope B (quartz).

FIRST PRINT. *Band Spectrum of Oxygen*, tube No. 1. —This spectrum extends, in an even series of bands, considerably into the violet. In the spectrum of oxygen on last plate, we count only six principal coarse lines or bands. In this print we count no less than fifteen. Probably from some difference in lighting up of the tube, one hydrogen line only shows in this spectrum, and the bright oxygen line doubling the hydrogen line in the spectrum on last plate though present is not nearly so conspicuous.

PRINT No. 2. *Water Gas.*—Tube marked H_2O, worked as above, colour of capillary red, but not so red as hydrogen. The principal lines of the latter are well distinguished. The oxygen spectrum is not so bright, especially towards the violet as in the last print.

THIRD PRINT. *Band Spectra of Oxygen and Nitrogen compared.*—Nitrogen tube and spectrum much the brightest. Oxygen spectrum towards red a comparatively even set of bands. Nitrogen, in sets of bands.

FOURTH PRINT. *Line and Band Spectra of Oxygen*

compared.—Line tube the brightest. Line spectrum very bright towards the red, but obscured towards the violet.

PLATE XXX.

CARBONIC ACID.

FIRST SPECTRUM. *Band Spectrum of Carbonic Acid.*—Spectroscope C. Tube marked C A of rather large bore, worked by large coil, much stratification extending even through the capillary, stream of capillary light, bright and of silvery grey green tint. Spectrum much filled up by obscure sets of bands or lines, except in the positions occupied by a bright line in the centre and a dark space more towards the violet. F hydrogen shows to the extreme left. The other hydrogen lines are not seen. Note sharp bright line separated from main body of the spectrum towards the red.

SECOND PRINT. Spectroscope C.—This was a tube marked SO_3. The light was pearly white. The spectrum turned out to be carbonic acid, probably from some impurity in the tube. See also second and third prints on PLATE XXXV. The tube was worked by the large coil and two weak bichromates.

THIRD PRINT. *Line Spectrum of Carbonic Acid.*—Spectroscope A. Condenser in circuit. Tube filled with stream of white light. Compare line spectra of oxygen and of coal gas taken with same instrument.

PLATE XXXI.

CARBONIC ACID (continued).

First Print. Spectral image, taken with spectroscope A, of *capillary part of carbonic acid tube* (C A) wide slit. Stratification well seen. Print from original negative not enlarged.

The three remaining spectra on this plate were taken with spectroscope B.

Second Print. *Carbonic Acid Tube, Band Spectrum.* —This spectrum as taken with the quartz instrument, though the same, differs somewhat in actual appearance from our print on last page. The two left-hand single lines are absent. The left-hand edge of the centre part of the spectrum is comparatively brighter. The bright band and dark interval before referred to are still more strongly defined.

Beyond the bright band and next to the dark interval which nearly ends the spectrum on the last plate, we get in our present spectrum a set of six lines or bands, the first only of which is faintly indicated in the spectrum taken with instrument C.

Third Print. *Line Spectrum of Carbonic Acid compared with Line Spectrum of Oxygen.*

Fourth Print. *Band Spectrum of Carbonic Acid compared with Band Spectrum of Oxygen.*

Some years ago Mr. Henry R. Procter and myself were much struck with the closeness in position of the three prominent bright lines or bands in the yellow,

green, green and blue, in hydrocarbon tubes as compared with like lines in an oxygen tube. The three lines were so nearly identical in position in the compared tubes that a fine pointer and high power eyepiece failed to distinguish apart their sharper margins. But for a certain want of accord in tint and intensity of the two spectra, we began to suspect the identity of the oxygen spectrum, and Mr. Procter even conjectured that oxygen might have only a continuous spectrum, and that the bright lines might arise from carbon impurity in the O tubes.

Our compared photographic spectra lie much more towards the violet end of the spectrum (beginning with the more refrangible of the three lines or bands above referred to), but it is pretty clear from an examination of them that, in this part of the spectrum at least, the spectra differ considerably. The line spectra approach the nearest in position, but there is a marked and distinct character to each of these. The band spectra are widely different. The smooth and even character of the band spectrum of oxygen contrasts strongly with the sharper and more defined lines and bands of the carbon spectrum. Some few lines only towards the violet of carbonic acid appear to correspond with bands in the oxygen spectrum. The one extremely bright line or band in carbonic acid is conspicuous for its absence as such in oxygen.

PLATE XXXII.

COAL GAS.

First Print. *Band Spectrum of Coal Gas.*—Spectroscope C. Stream in tube whiter and brighter than carbonic acid, much stratification, exposure 15 minutes. Spectrum as reading from the red composed of four faint single lines followed by an evenly lighted broad continuous portion, crossed by many well-defined bright lines or narrow bands.

This continuous portion terminates with a most brilliant band or set of lines shading off towards the violet, which is immediately succeeded by a fairly strong and then a faint line as the last indication of the spectrum.

Compared with the Hydrogen spectrum, F is seen faintly to the extreme left, followed by the two short lines seen in the Hydrogen spectrum between F and near–G. Next comes an outstanding sharp line, also seen in the Carbonic Acid spectrum.

Near–G Hydrogen is next seen as a well-defined line on the edge of the continuous portion. The very bright line exactly in the centre of the print does not fall in the place of *h* but of a line a little beyond *h*, also seen in the Hydrogen spectrum. The spectrum forms a fine photograph, and nearly all that is seen in the plate is got out in the print.

Second Print. *Cyanogen.*—Tube lent to me by Mr. W. G. Lettsom, lighted up easily with a white glow, lines and bands sharper and more separated by

dark intervals than in the Coal Gas spectrum. Assuming the first (single) line on the left to be near–G Hydrogen, a few lines in the spectra of coal gas and cyanogen fairly correspond, and the general character of the two spectra is somewhat alike. They, however, differ in detail.

Third Print. *Coal Gas Tube.*—Spectroscope B. The general aspect of the spectrum is that of the first print, except that the lines are not so well defined, but blend into bands.

The especially bright band towards the violet is easily recognised, and beyond it extend three bright bands not seen in the large spectrum.

PLATE XXXIII.

COAL GAS (continued).

First Print. *Line Spectrum of Coal Gas.*—Condenser in circuit, exposure 20 minutes. Note former remarks on line spectra of oxygen and carbonic acid.

Second Print. *Line and Band Spectra of Coal Gas compared.*—The line spectrum commences with the band and bright line so conspicuous in the first print, and then succeed two other bright lines or bands, with fine lines between. The last band towards the violet in the line spectrum corresponds with the very bright band in the band spectrum.

Third Print. *Coal Gas Band Spectrum compared*

with Hydrogen Lines.—Spectroscope A. Print from the original negative, not enlarged; near–G is seen on the edge of the first bright band or set of lines in coal gas.

FOURTH PRINT. *Spark in Coal Gas at ordinary pressure.*—Same spectroscope as used for Arc and Spark Spectra. Print from original negative, which was afterwards enlarged to form prints on PLATES VI. and XXVI.

PLATE XXXIV.

OTHER HYDROCARBONS.

FIRST PRINT. *Olefiant Gas.*—Tube fairly bright. Spectroscope A. A broad bright band, (probably a set of lines or bands), and a nebulous bright line beyond, towards the violet, are very marked in this spectrum. As these are only feebly indicated in the other two spectra of this gas, they may probably have depended upon the lighting up of the tube.

SECOND PRINT. *Olefiant Gas.*—Spectroscope C. Spectrum with well-defined lines. The faint one towards the extreme left seems to be one of the lines in Hydrogen intermediate of F and near–G. As in the case of coal gas, near–G is on the margin of the continuous part of the spectrum, while the fifth bright line in the spectrum falls upon the place of the line in Hydrogen just beyond *h*.

The bright broad band in the first print is indicated by a few faint lines.

THIRD PRINT. *Olefiant Gas.*—Spectroscope B. The set of two double and two single bright lines in the last spectrum is easily recognised on a smaller scale. Three other bright bands are seen towards the violet.

FOURTH PRINT. *Turpentine Vapour.*—Tube not bright, large coil used. Exposure fifteen minutes. As might be expected, the print bears a likeness to the Olefiant spectrum,

FIFTH SPECTRUM. *Ether Vapour.*—Spectroscope C, tube difficult to light up. What is seen of spectrum resembles Olefiant and Turpentine spectra.

PLATE XXXV.

SULPHUR.

FIRST PRINT. *Sulphur.*—A short German tube, with small bulbs and a bent capillary part. The bulbs contained a small quantity of solid sulphur. The tube was suspended, and the lower bulb heated by a spirit-lamp. When the sulphur was partly melted, one half of the capillary was white in colour and the other half red. As the heat was gradually applied the spectrum of sulphur of first order was seen to spread up the tube as a set of bright bands, which by management of the lamp could be kept at a definite height. The spectrum independent of the sulphur vapour was found to be hydrogen, with the principal lines very bright. Photographs were first tried with A and B spectroscopes, but were not satisfactory. Several plates were subsequently

taken with spectroscope C. We tried to take the spectrum lower half sulphur and upper half hydrogen, but failed, probably for want of proper adjustment of the lamp. In each case we found only the sulphur spectrum on the plate. The plates were all much alike, and only differed in distinctness of the bands.

SECOND PRINT. *Another print of SO_3 Tube Spectrum.*—Spectroscope C, see PLATE XXX., where by comparison the spectrum is seen to be a carbonic acid one, arising we presume from impurity in the tube.

THIRD PRINT. *SO_3 Tube.*—Spectroscope B, same result as above. Compare with carbonic acid spectra, PLATE XXXI. The slit must have been a little wider, or the tube less bright in this instance, as the spectrum is more continuous and the lines not so sharp.

PLATE XXXVI.

FIRST PRINT. *Silicic Fluoride Spectrum.*—Tube easily worked, capillary a beautiful violet, bulbs golden brown. Under influence of large electro-magnet, stream of light became less violet and more red in tint, contracted itself, and ran through the bulbs from pole to pole. At the same time a slight noise, between a whistling and a metallic ring of high pitch, was heard.

The stream was curved in the bulbs towards one side or the other as the current was reversed. Good photograph, lines some twenty-four in number, sharp, and well separated. A fine shaded group commences the spectrum towards the red end. This group in

the spectroscope is of a brilliant violet tint, and at once identifies the spectrum.

SECOND PRINT. *Silicic Fluoride Spectrum.*—Spectroscope B. The spectrum does not seem more extended into the violet in this instance, but a band or set of lines towards the centre is brightened up. A second photograph was taken with the tube under the influence of the electro-magnet, same time of exposure. The image was identical, but very decidedly fainter.

THIRD PRINT. *Tin Chloride.*—Spectroscope B. This tube was very difficult to photograph. The small coil only did not sufficiently light the tube, the large coil was too much for it. The discharge was in the form of a slender bright green thread running through the tube. For a short time all went well, after that the stream intermitted and almost broke up, and flashes of light only took its place. At the same time the metal lines grew fainter in the spectrum, and the bulbs of the tube were filled with a yellowish flare. These, on subsequent examination, were found covered with a whitish crust. Only one fair plate was obtained, of which a print is given. Some fine metallic looking lines seen in the spectrum do not come out in the photograph.

FOURTH PRINT. *Iodine Tube.*—This was lighted by the small coil only. The photograph shows two sets of bands, each gradually degrading towards the violet, with a dark interval between them.

Many fine lines seen in the tube spectrum do not appear in the photograph.

FIFTH PRINT. *Spark in Iodine Vapour.*—A bulb

similar to that employed for spark in coal gas was used. The ends were lightly plugged with cork and the iodine vapourised by a spirit-lamp.

When the vapour filled the bulb, the spark spectrum as seen through it with a small direct vision spectroscope showed marked absorption bands.

Traces of these (better on the plate than in the print) may be found on the photograph.

A *Chlorine Tube*, it has been mentioned, baffled us. We tried it with the small coil, and exposure gave no image apparently for want of brightness. We then tried it with the larger coil. At first the tube shone with a yellowish green stream running from pole to pole, the bulbs being filled with a somewhat dull purple glow. Almost suddenly one pole and then the other changed to a brighter and whiter purple. One pole then changed to a rich salmon colour, the opposite pole remaining white surrounded by a purple glow. Current reversed, and both bulbs then became salmon colour, with considerable stratification. Ultimately the capillary became a pinkish white, one pole a red buff and the other a bright lilac. The yellow green line was then altogether lost.

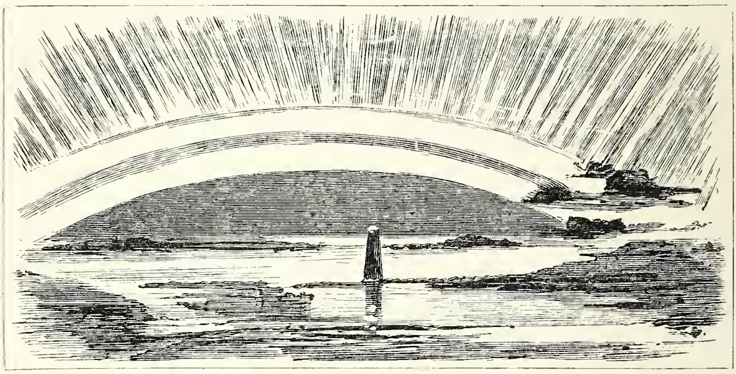
On reversing current, the poles changed. The spectrum when the plate was examined was found to be nitrogen.

NOTE TO OXYGEN SPECTRUM.

Since the foregoing has been penned, Professor Draper's interesting paper and photograph have been made public. The solar spectrum from about 4350 to 3900 is photographically compared with the lines of oxygen, as seen in spark in air, and coincidences are shown, principally at the double lines 4319 4317, 4190 4184, and the triple line 4076 4072 4069. The air spark spectrum in Professor Draper's photograph, making allowance that it is on a scale of three times the size, and that it has less of continuous spectrum filling up between the lines, very closely resembles our air spectrum fine slit Plate I. Most of the lines in each are easily compared and identified. The three principal nitrogen lines are recognised, the one near 4000 by its strength and brightness, and the other two by their fuzzy expanded character: the oxygen lines by their comparative sharpness. In our solar spectrum, we find faint traces of the bright lines which are alluded to by Professor Draper, and their character suggested. It is curious that these bright lines in the solar spectrum should have been so long overlooked, or not more closely examined; for in the spectrum taken from an illuminated cloud with a large direct vision spectroscope their existence is readily detected. Doubtless they have been generally regarded as spaces or effect of contrast between the dark lines, and it is indeed only after a certain amount of study whether of the spectrum or of a photograph, that they appear to stand forward from among the dark lines in an independent character. Judging from his paper, Professor Draper seems to have found with his incomparably larger and more perfect

apparatus, the same sort of difficulty in the tube work that we experienced in ours on a smaller scale. Professor Draper makes the remark, 'I do not think that in comparisons of the spectra of the elements and sun, enough stress has been laid on *the general appearance of lines apart from their mere position*; in photographic representations this point is very prominent.'

Our set of Plates amply illustrates the justice of this remark of the Professor's.



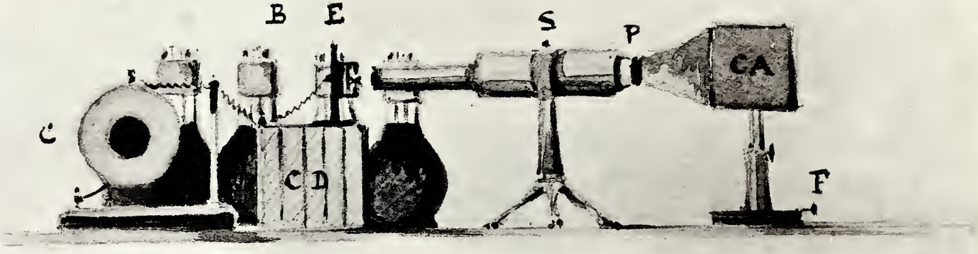
Aurora, double Arc and Streamers, Kyle Akin, Isle of Skye, Sept. 11, 1874, 11 P.M. From a sketch by J. Rand Capron.

INDEX TO ARC AND SPARK SPECTRA.

INDEX TO THE GASES.

LONDON: PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
AND PARLIAMENT STREET

APPARATUS AS USED FOR SPARK SPECTRA



C Coil.

B Bichromates.

CD Condenser.

E Electrodes.

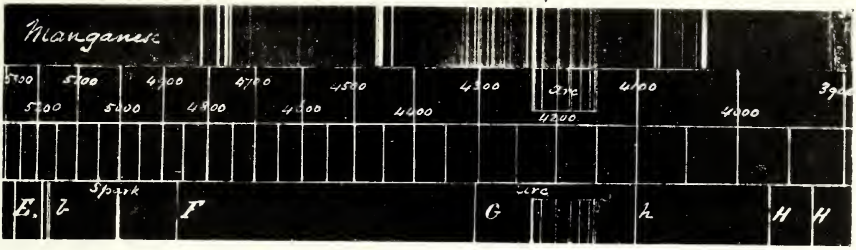
S Spectroscope

P Projecting lens

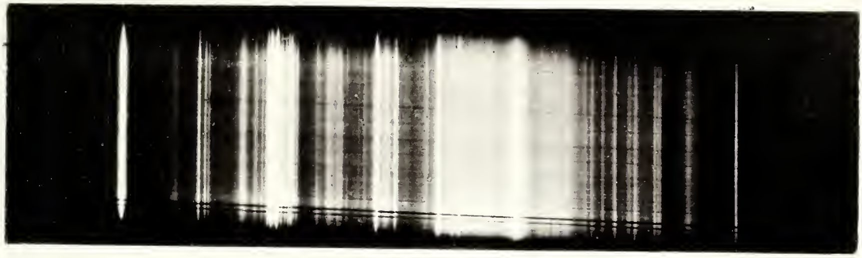
CA Camera and bag

F Fine adjustment

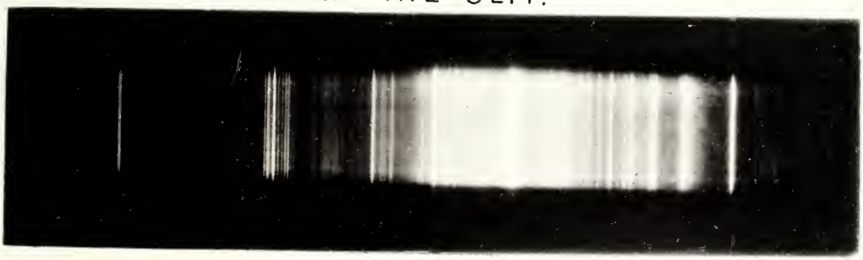
SCALE.



AIR. WIDE SLIT.



AIR. FINE SLIT.



ARSENIC. SPARK.

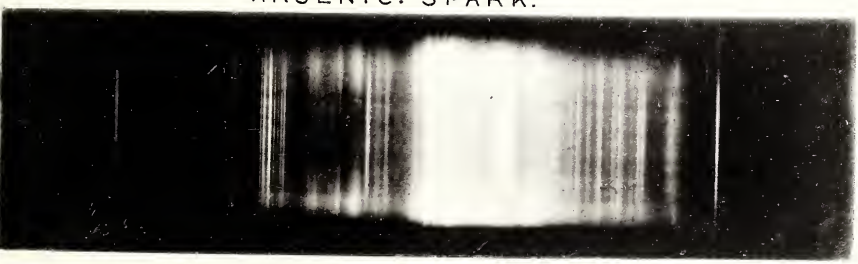
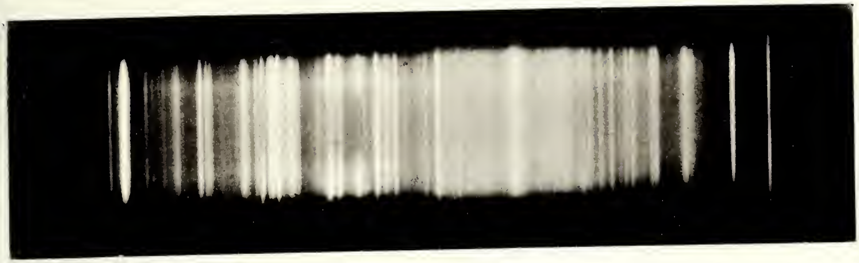


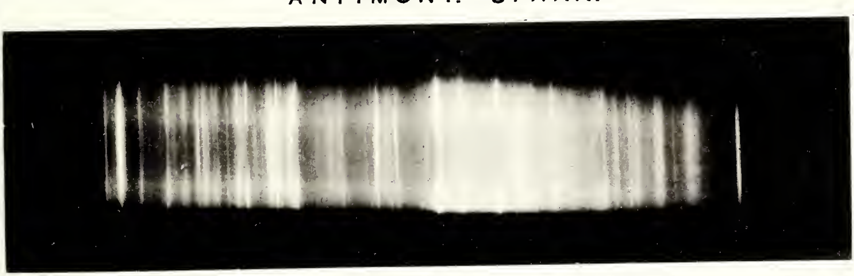
Plate II.

ALUMINIUM. SPARK.



ALUMINIUM. ARC.

ANTIMONY. SPARK.



ANTIMONY. ARC.

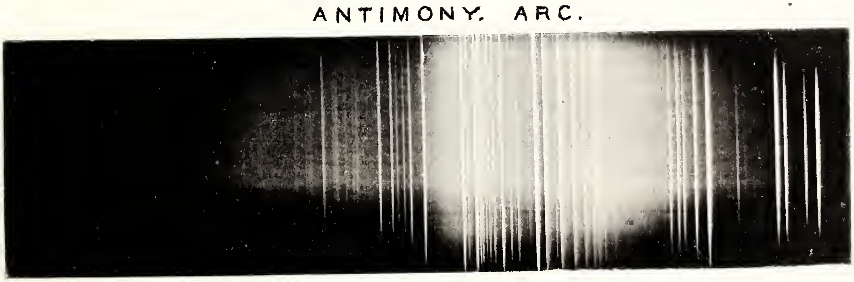
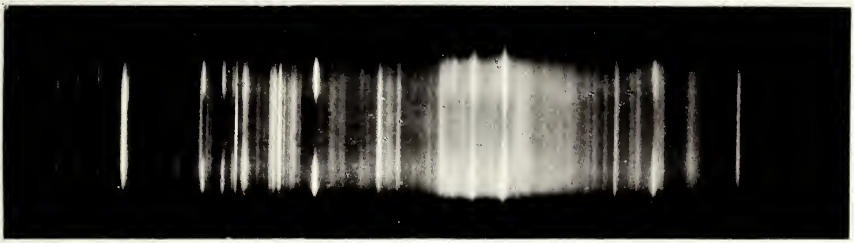
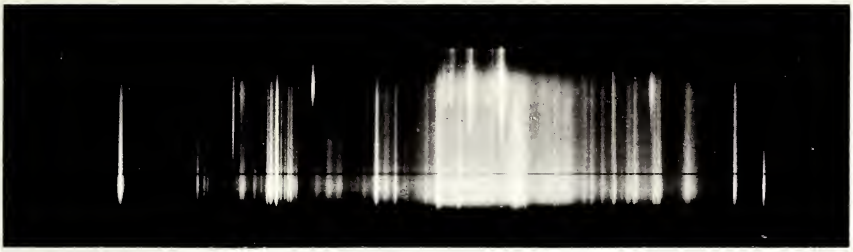


Plate III.

BISMUTH. SPARK.

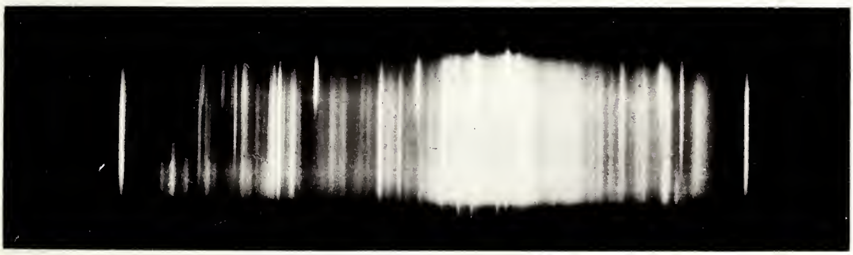


BISMUTH. SPARK.



NICKEL.

BISMUTH. SPARK.

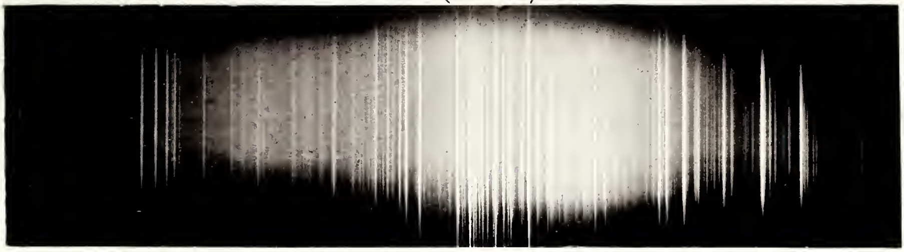


TELLURIUM.

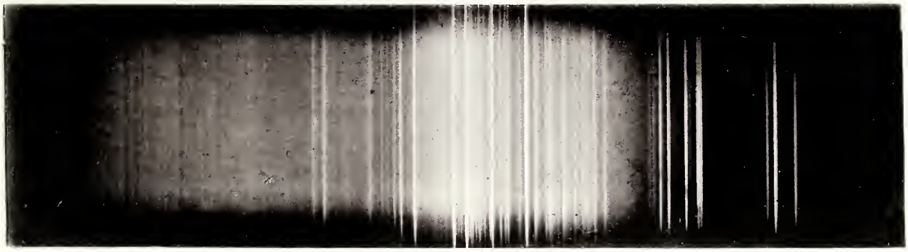
BISMUTH. ARC.

BARIUM. SPARK.

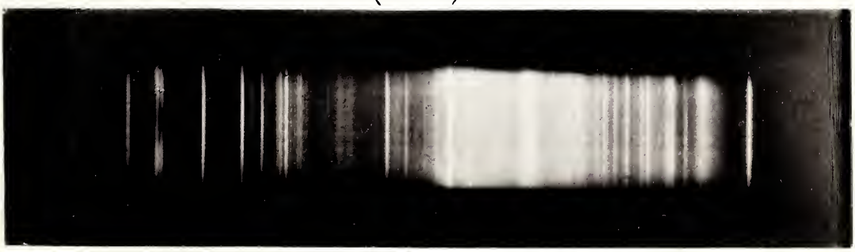
BERYLLIUM. (IRON) ARC.



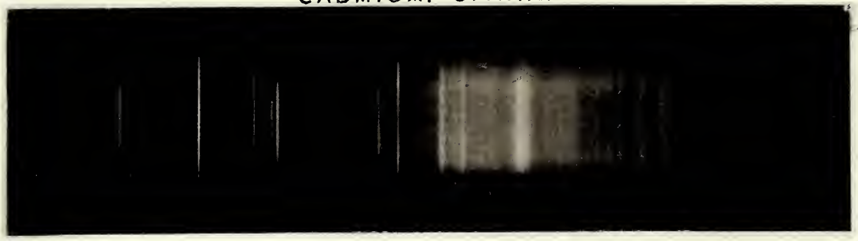
BORON. ARC.



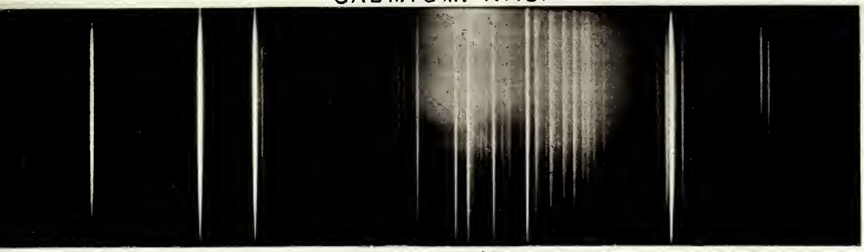
CALCIUM. (ZINC) SPARK.



CADMIUM. SPARK.

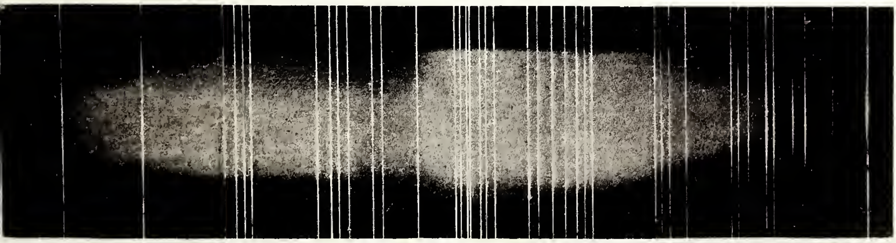


CADMIUM. ARC.



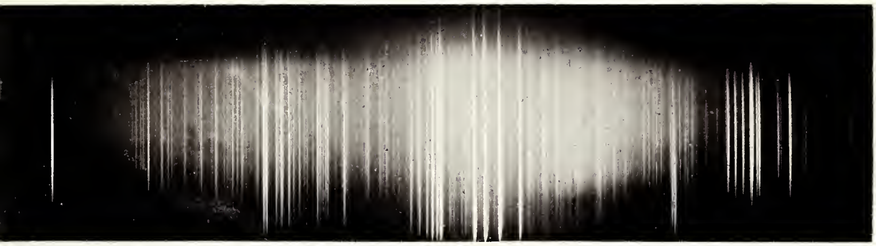
CARBON POINTS.

CARBON POINTS RULED OUT.

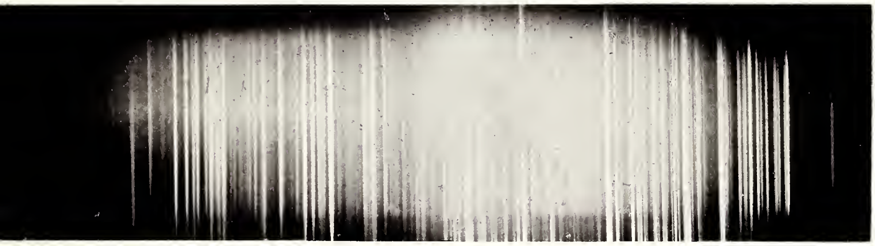


SPARK IN COAL GAS.

CHROMIUM. ARC.



COBALT. ARC.



COPPER. SPARK.

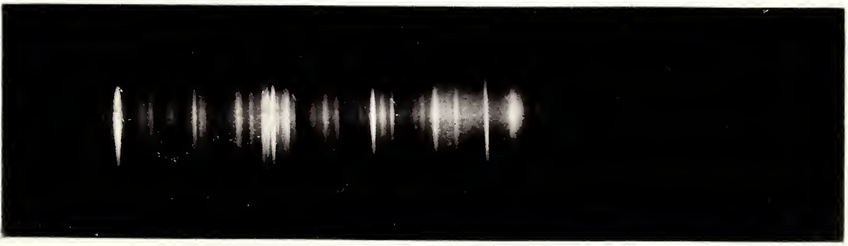
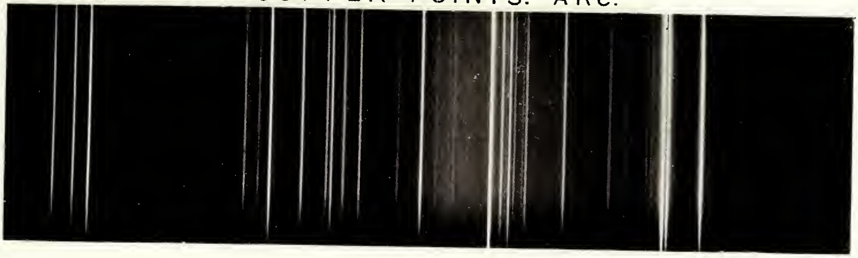


Plate VII.

COPPER POINTS. ARC.



ALLOY. COPPER, GOLD & SILVER. ARC.

DIDYMIUM. ARC.

ERBIUM. ARC.

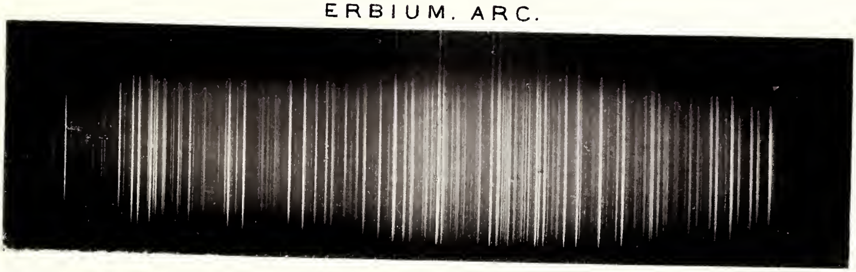
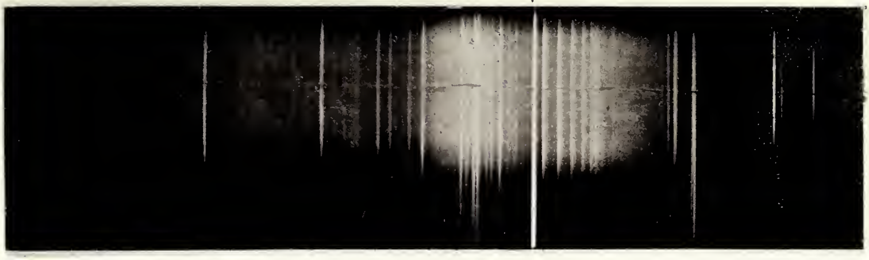
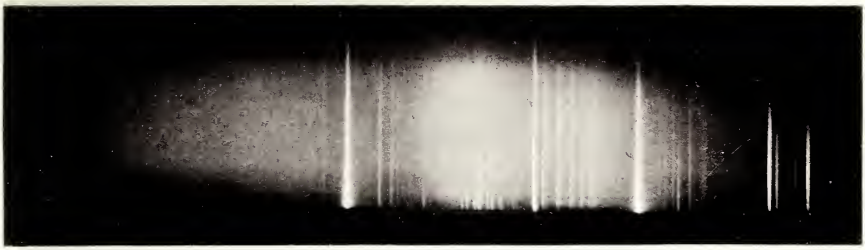


Plate VIII.

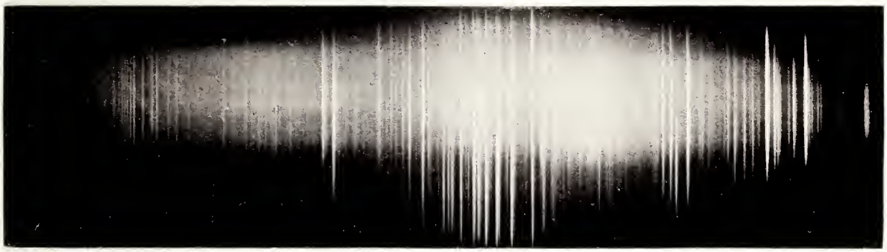
GOLD. ARC.



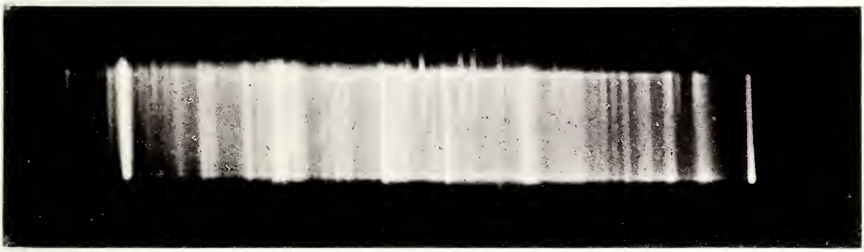
INDIUM. ARC.



IRIDIUM. ARC.

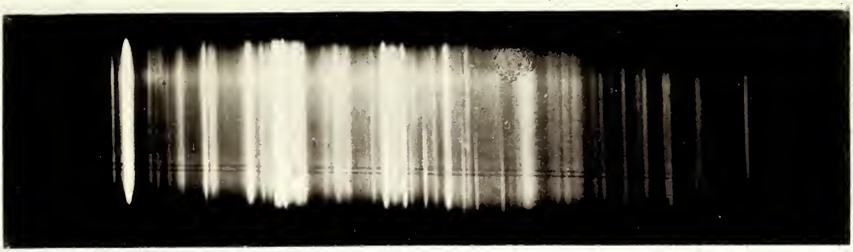


IRON. SPARK.



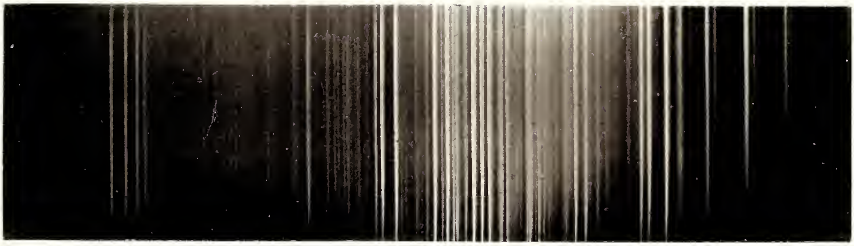
COPPER.

IRON. SPARK. (AND COPPER.)



IRON. ARC.

IRON. ARC.



IRON & SELENIUM. SPARK.

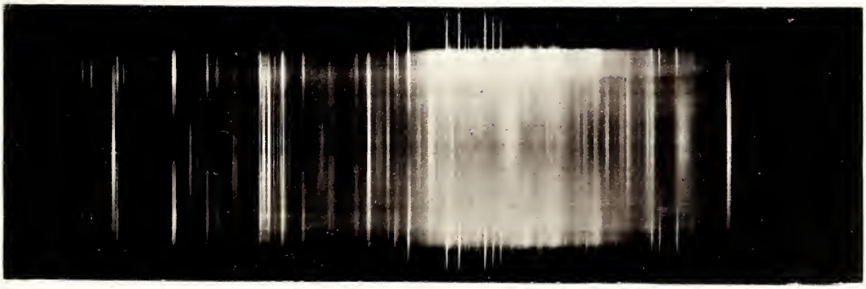
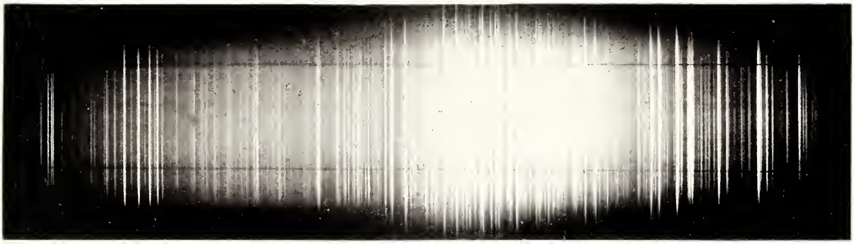


Plate X.

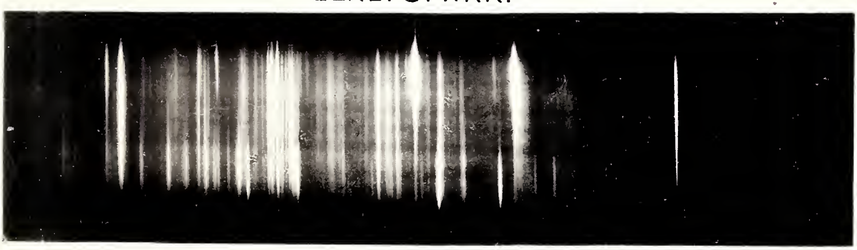
IRON, METEORIC. ARC.

IRON, METEORITE. ARC.



LEAD. ARC.

LEAD. SPARK.



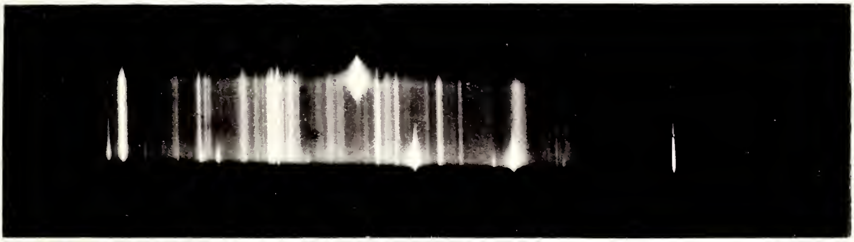
ANTIMONY.

Plate XI.

LEAD. SPARK.

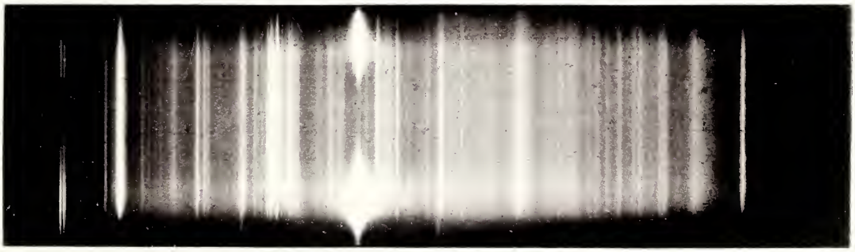
MAGNESIUM.

MAGNESIUM. SPARK.

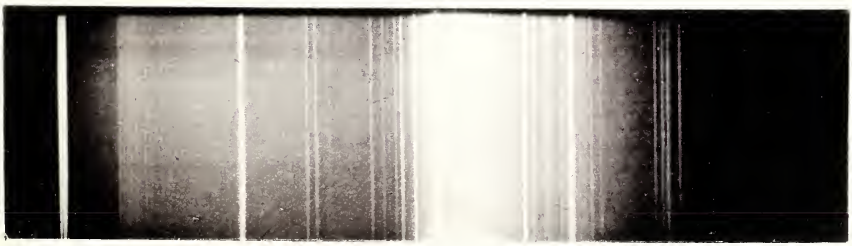


LEAD.

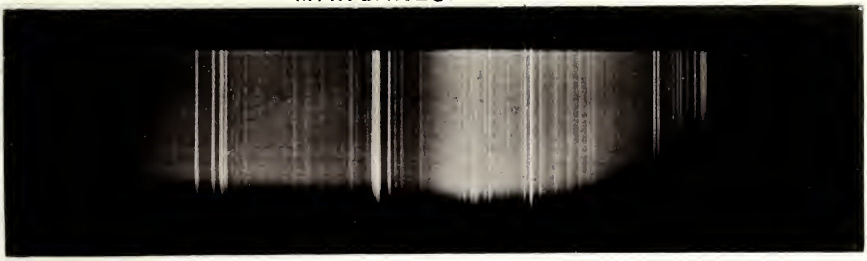
MAGNESIUM. SPARK.



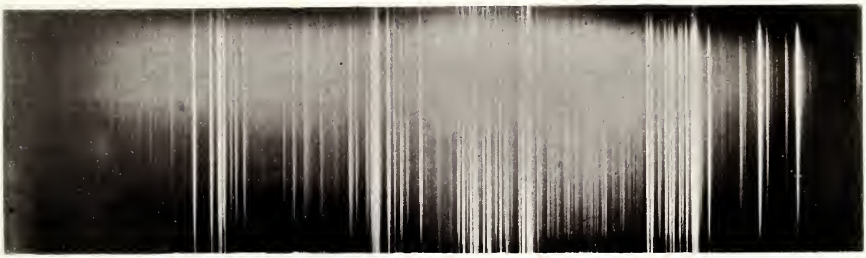
MAGNESIUM. ARC.



MANGANESE. ARC.

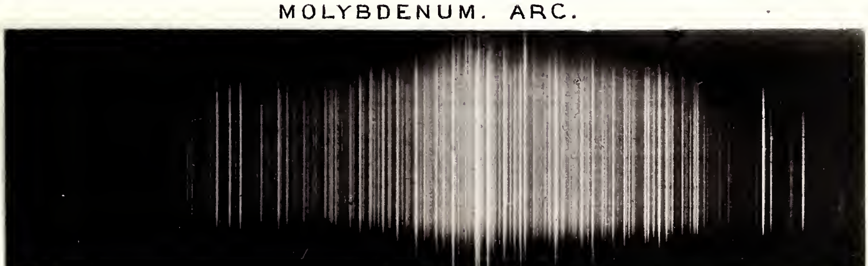


MANGANESE. ARC.

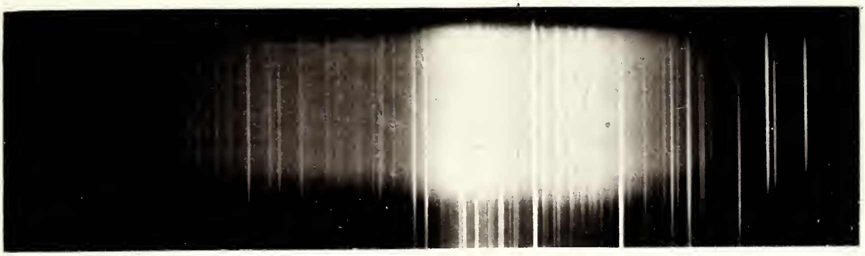


MERCURY. SPARK.

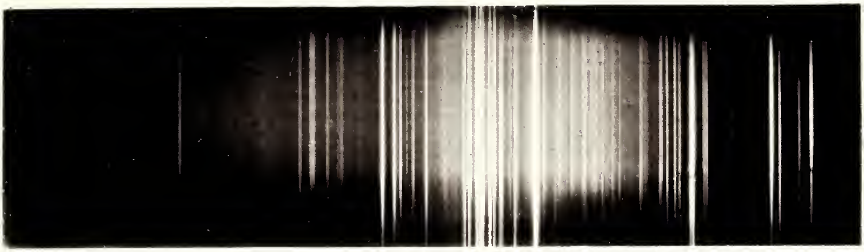
MOLYBDENUM. ARC.



NICKEL. ARC.

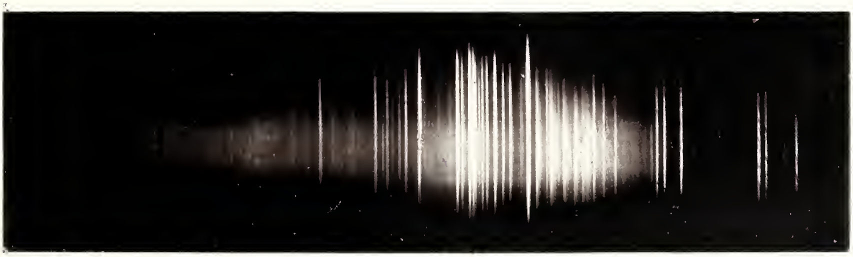


NIOBIUM. ARC.

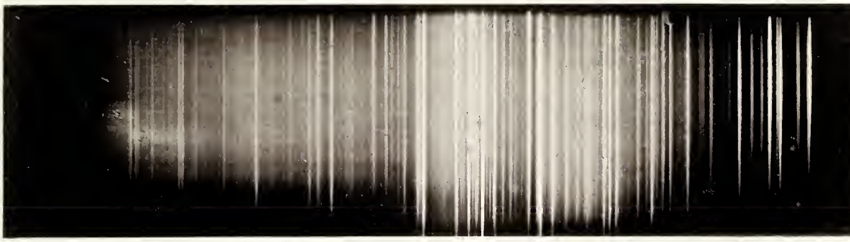


PALLADIUM. ARC.

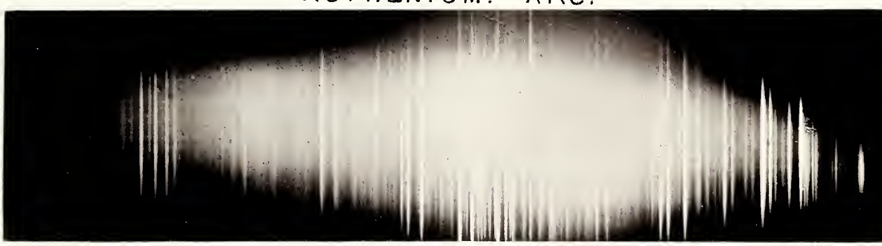
PLATINUM. ARC.



RHODIUM. ARC.



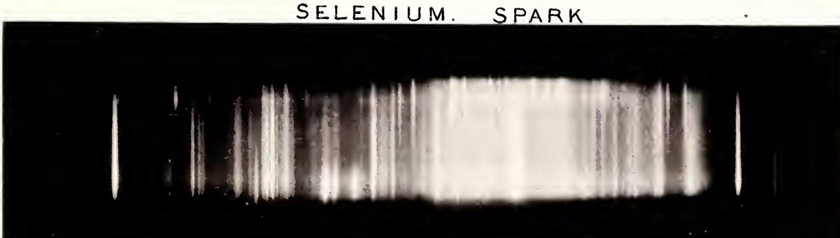
RUTHENIUM. ARC.



SELENIUM. SPARK.

TELLURIUM.

SELENIUM. SPARK

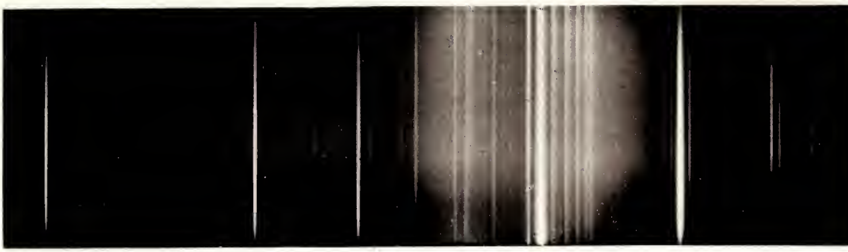


ALUMINIUM.

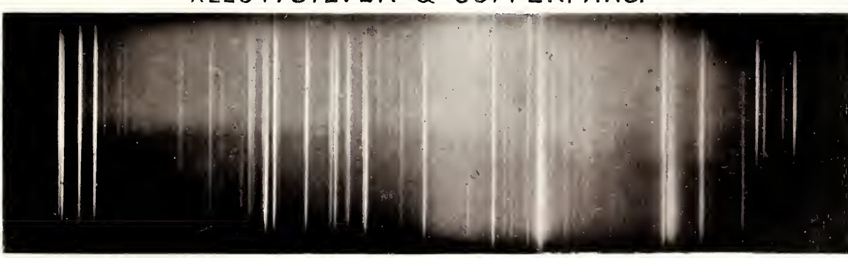
Plate XV.

SILVER SPARK.

SILVER ARC.



ALLOY. SILVER & COPPER. ARC.



SOLAR SPECTRUM.

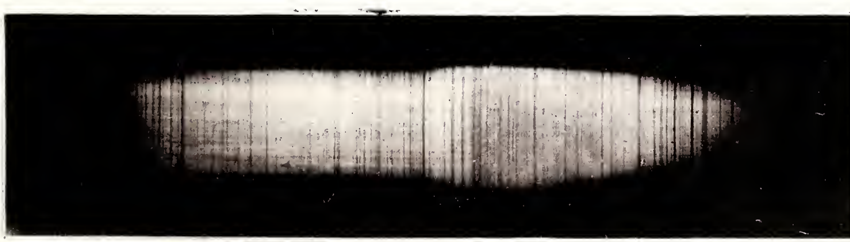
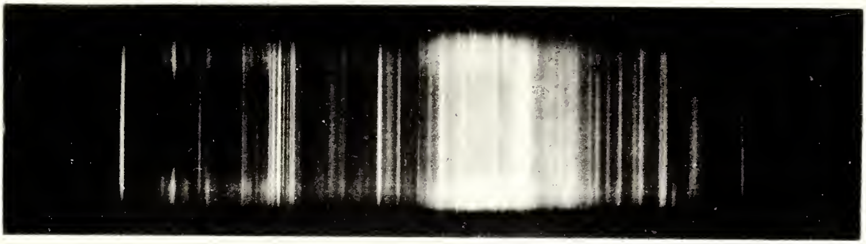


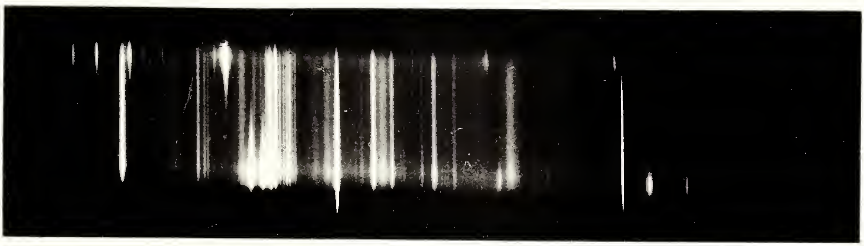
Plate XVI.

STRONTIUM. SPARK.

TELLURIUM. SPARK.

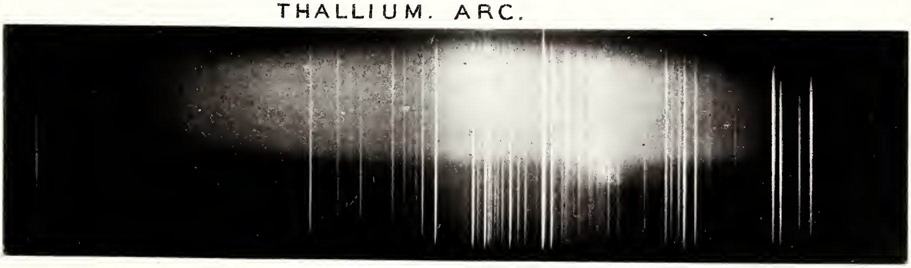


THALLIUM. SPARK.

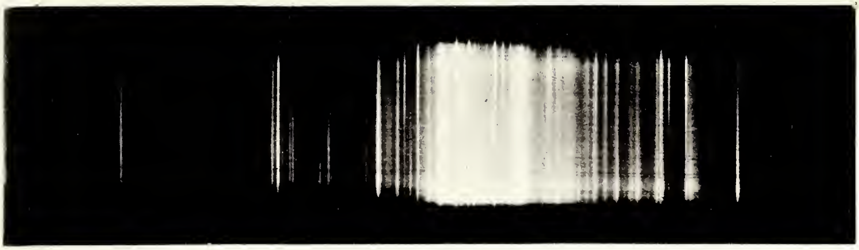


INDIUM.

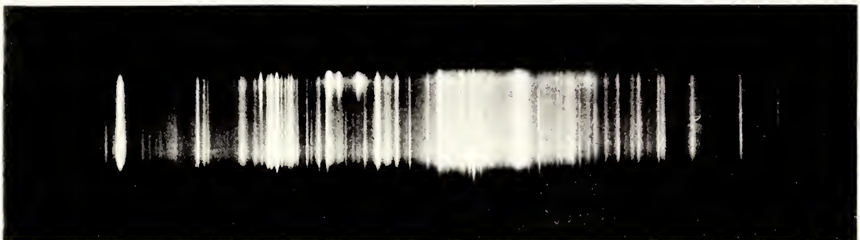
THALLIUM. ARC.



TITANIUM. SPARK.

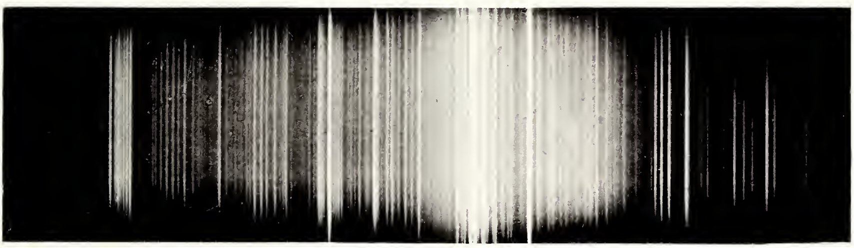


TITANIUM & ALUMINIUM. SPARK.

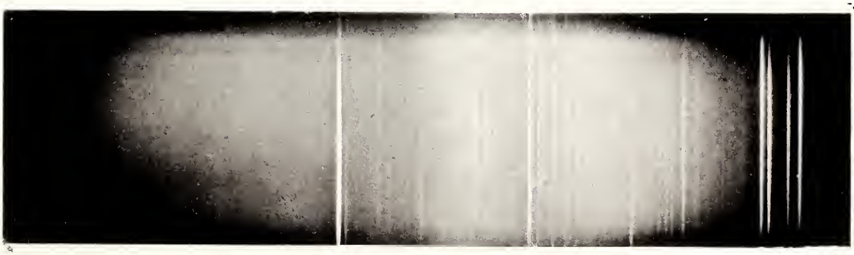


PALLADIUM.

TITANIUM. ARC.



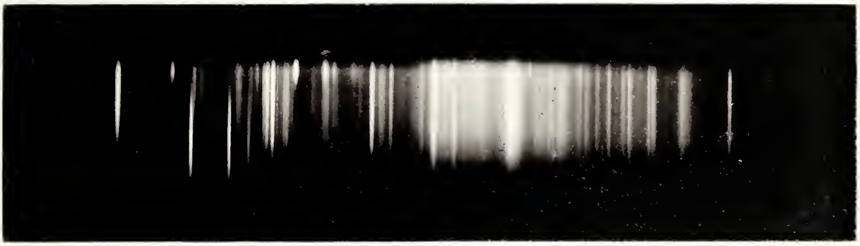
TIN. ARC.



TIN. SPARK.

ZINC.

TIN. SPARK.



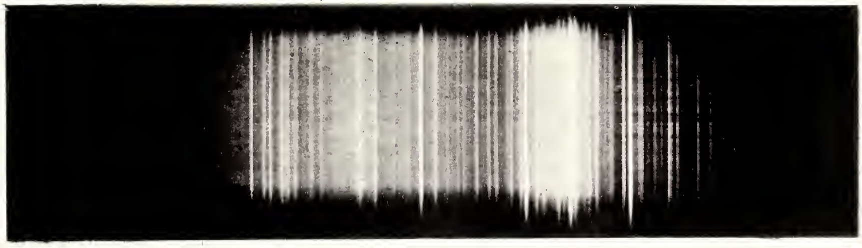
ZINC.

URANIUM. ARC.

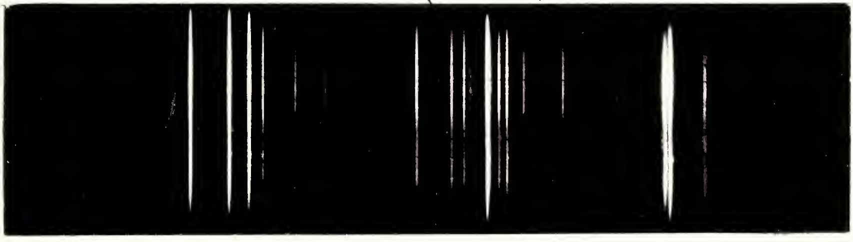
VANADIUM. ARC.

WOLFRAM. ARC.

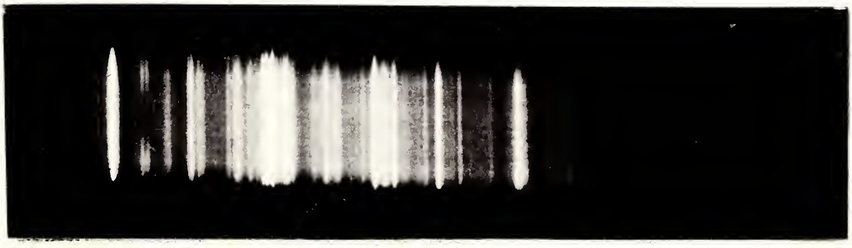
YTTRIUM. ARC.



ZINC ALLOY (BRASS.) ARC.

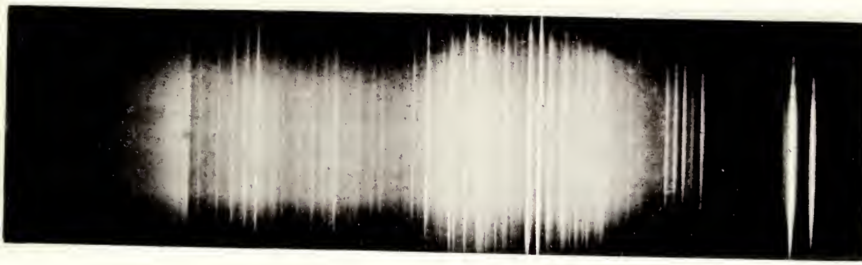


SAME. SPARK.



ZINC. ARC.

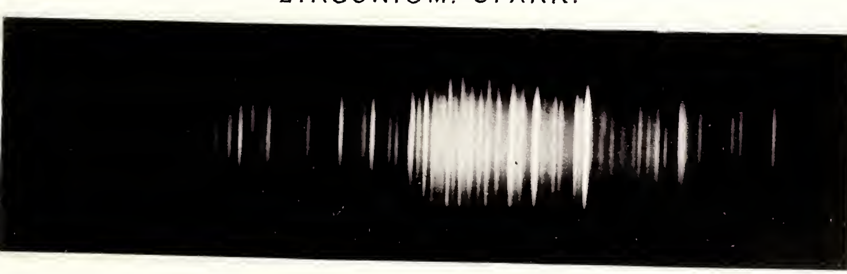
ZIRCONIUM. ARC.



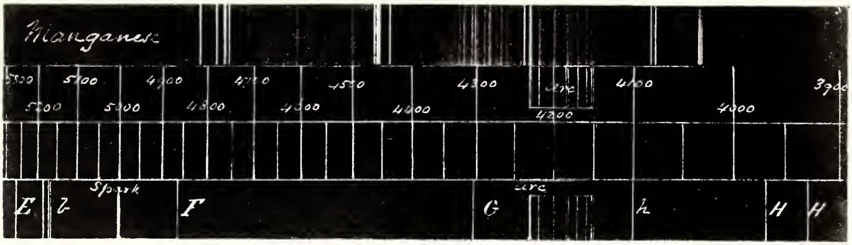
ZIRCONIUM. SPARK.

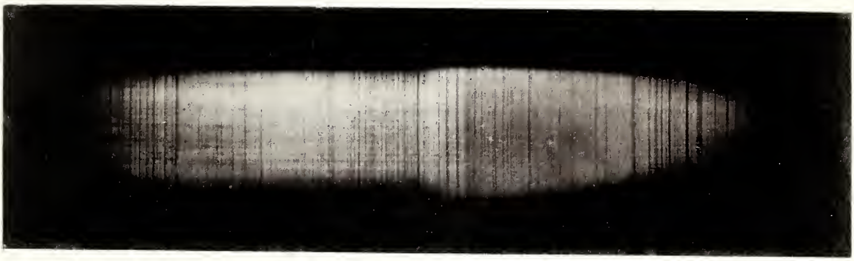
PALLADIUM.

ZIRCONIUM. SPARK.



SCALE.

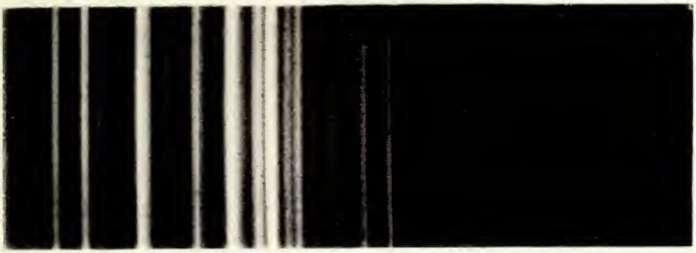




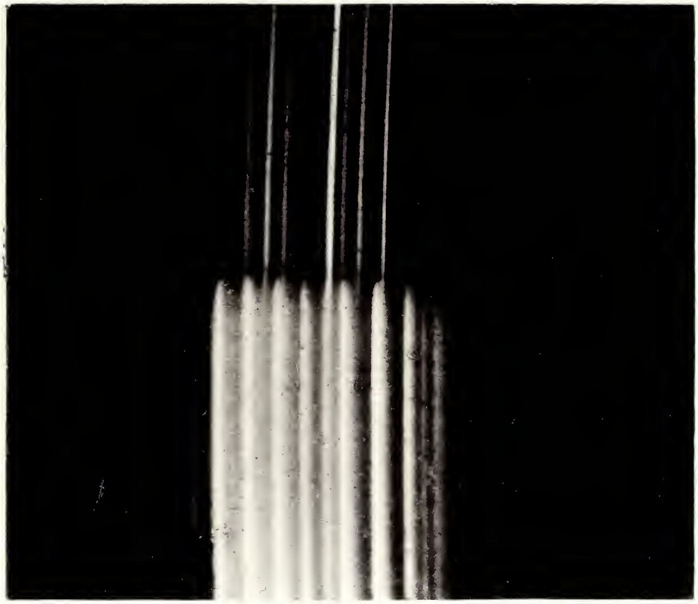
SOLAR SPECTRUM.

NITROGEN.

N LINE.

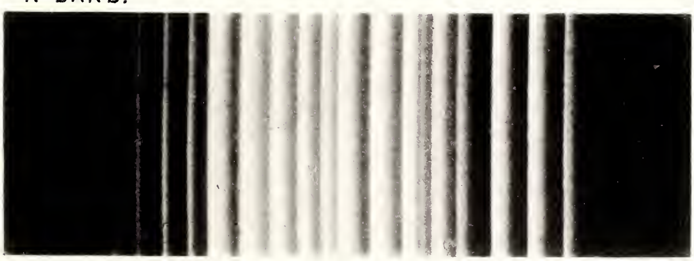


N LINE.



N BAND.

N BAND.



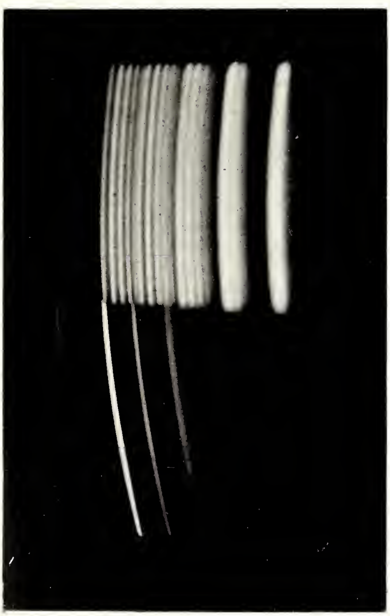
NITROGEN.

N. LINE QUARTZ.

N. BAND QUARTZ.

N. BAND.

N. BAND QUARTZ.



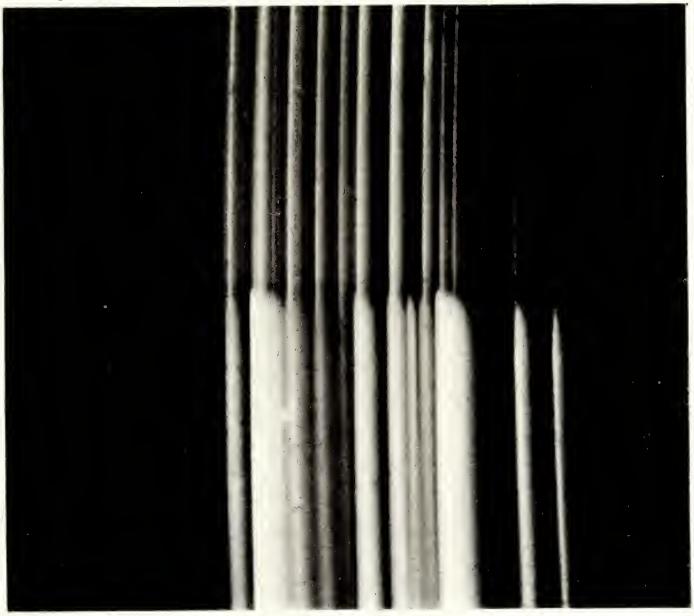
H

N. CAPILLARY QUARTZ.

N. BULB.

N VIOLET POLE.

N BAND CAPILLARY.



N VIOLET POLE.

N V.P. QUARTZ.

N CAPILLARY.

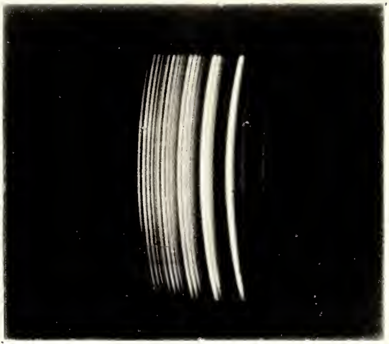
N V.P. QUARTZ.

NITROGEN.

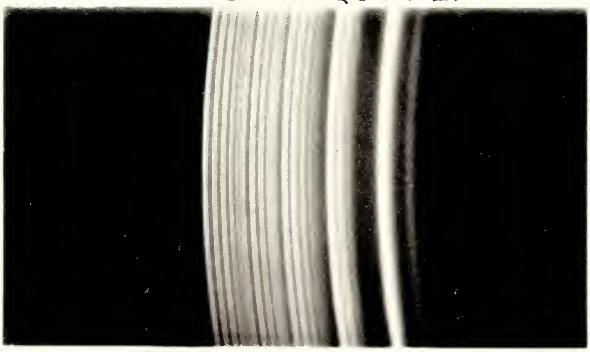
Plate XXV.

N WITH MAGNET.

N WITHOUT MAGNET.



AMMONIA. QUARTZ.



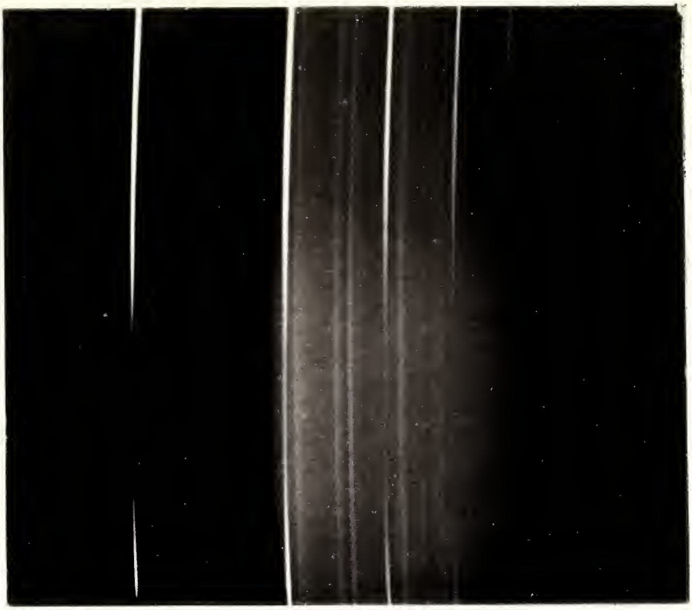
N LINE.

SPARK IN AIR.

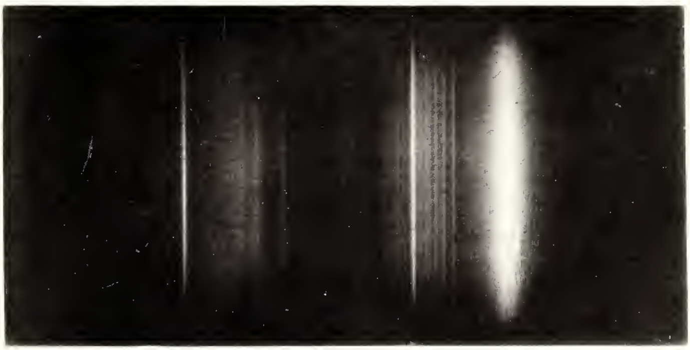
SPARK IN AIR.

SPARK IN C.G.

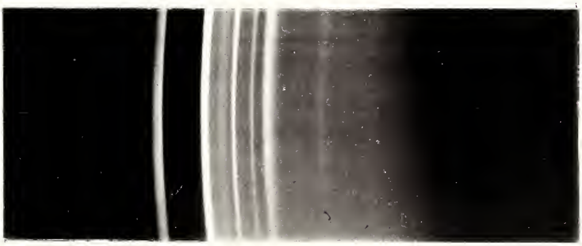
H TUBE.



H IN COAL GAS. h LINE EXPANDED.

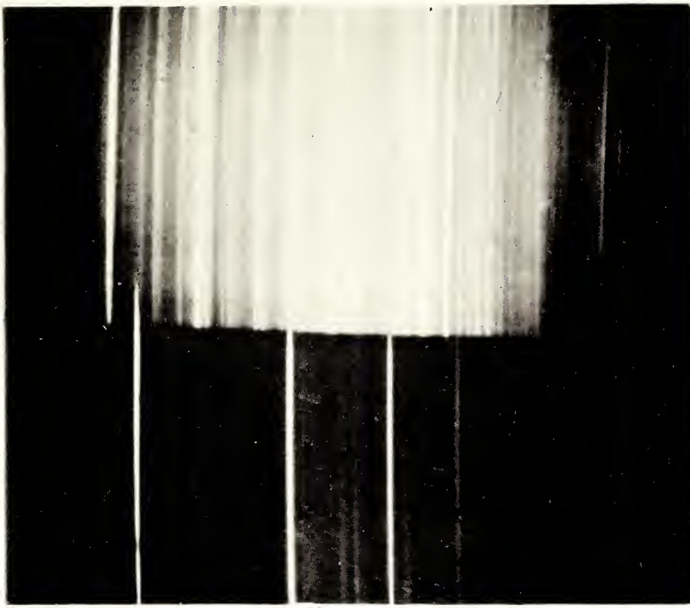


H TUBE. QUARTZ.



HYDROGEN.

SPARK IN AIR.



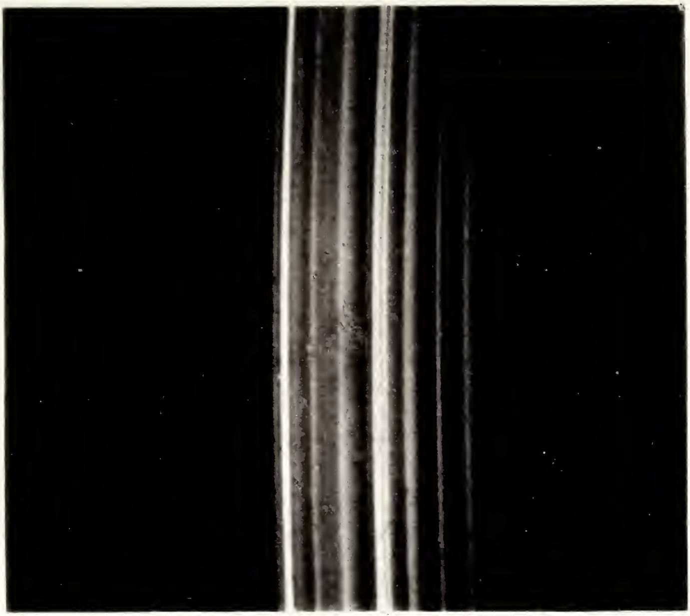
H TUBE.

SPARK IN COAL GAS.

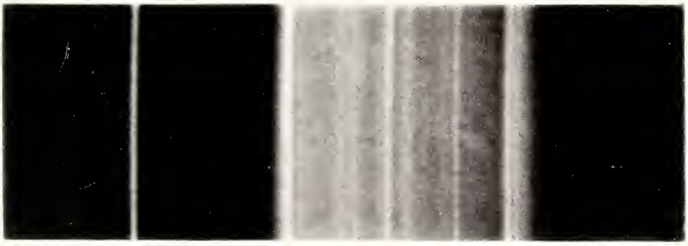
OXYGEN.

Plate XXVIII.

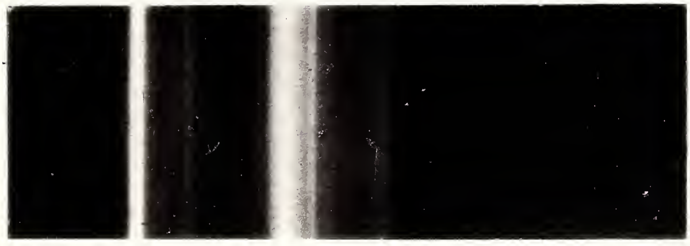
O BAND. TUBE No. 1.



O BAND. TUBE No. 2.



O LINE.

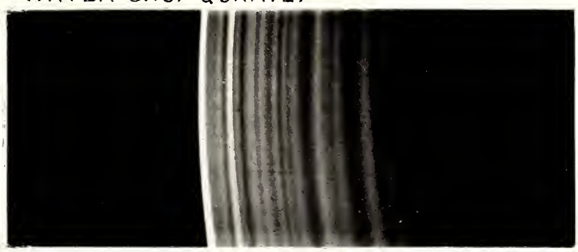


OXYGEN.

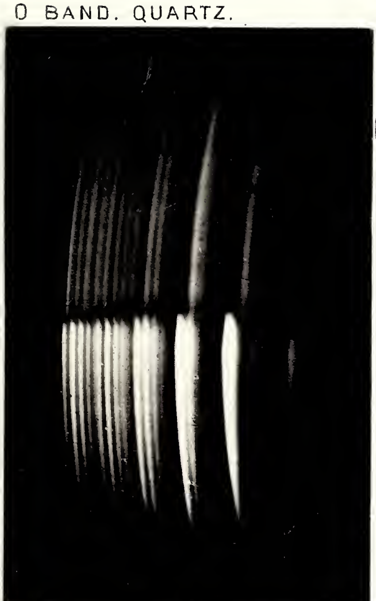
Plate XXIX

O BAND. QUARTZ.

WATER GAS. QUARTZ.



O BAND. QUARTZ.



N BAND.

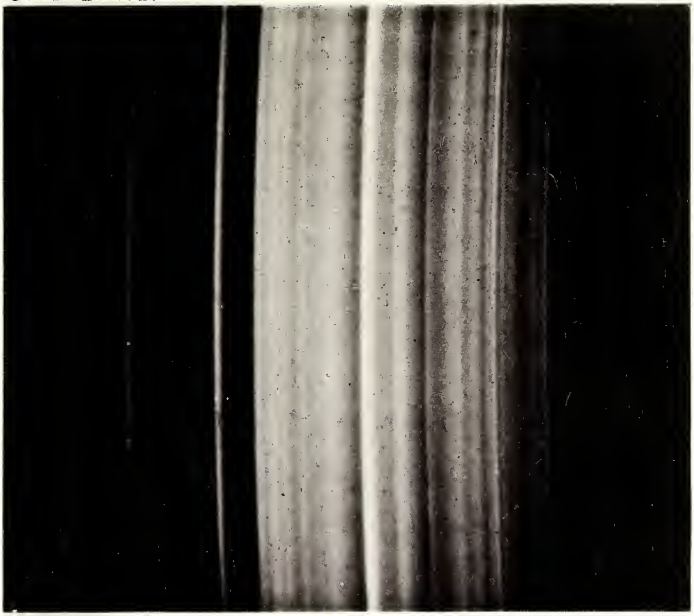
O LINE QUARTZ.

O BAND.

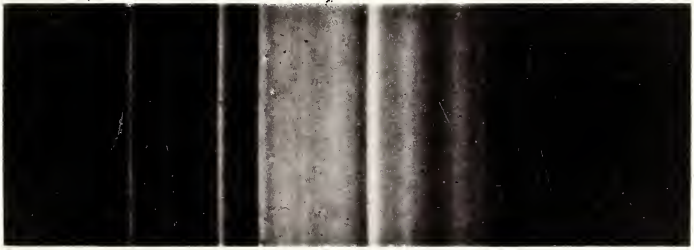
CARBONIC ACID.

Plate XXX.

C.O$_2$. BAND.



S.O$_3$. (FOR COMPARISON.)



C.O$_2$. LINE.

CARBONIC ACID.

Plate XXXI.

C.O_2 STRATIFICATION.

C.O_2 BAND. QUARTZ.

C.O_2 LINE.

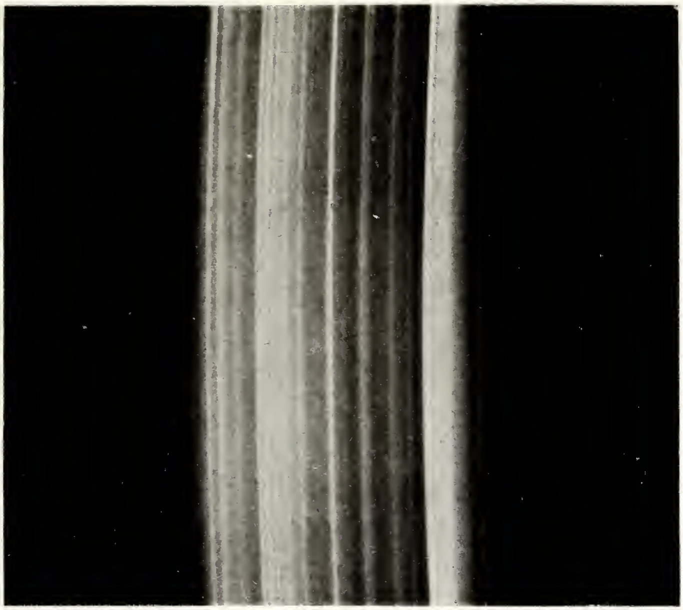
O. LINE.

C.O_2 BAND.

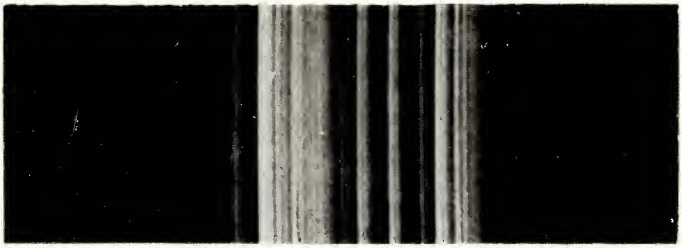
O. BAND.

COAL GAS.

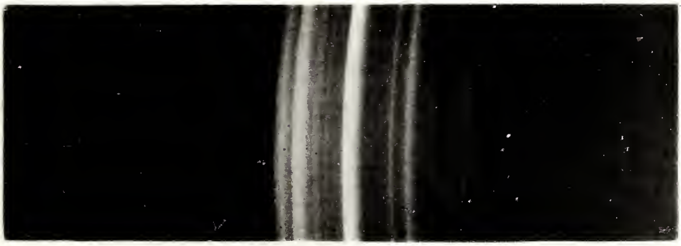
COAL GAS BAND.



CYANOGEN.



C.G. BAND. QUARTZ.



COAL GAS.

C.G. LINE.

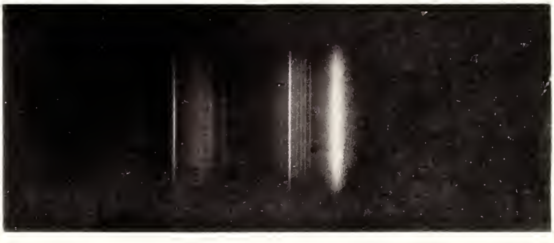
C.G. LINE QUARTZ.

C.G. BAND.

C.G. BAND.

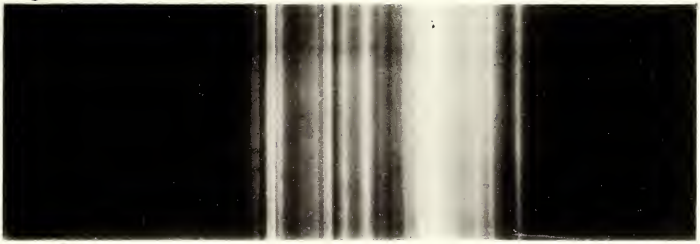
H

SPARK IN C.G.

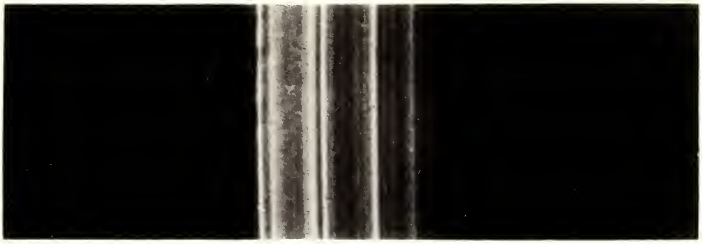


OLEFIANT GAS. *Plate XXXIV*

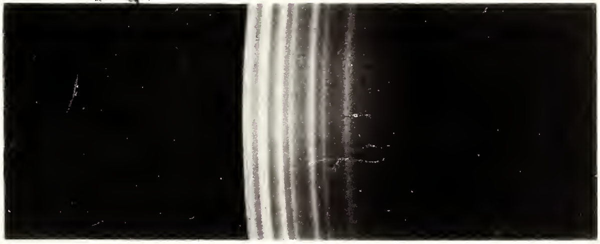
$C_2.\ H_4.$



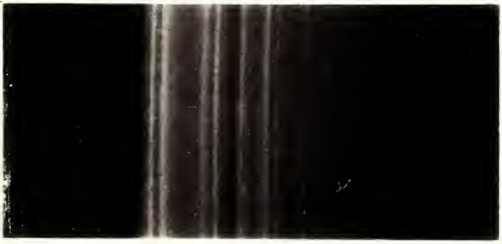
SAME.



SAME QUARTZ.

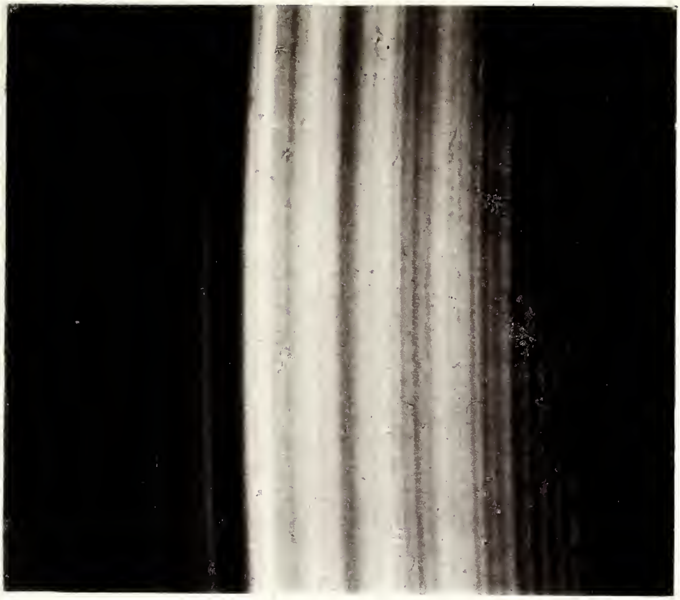


TURPENTINE VAPOUR.

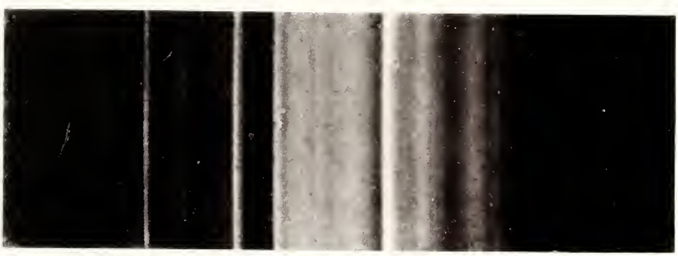


ETHER VAPOUR.

SULPHUR.



S.O3.



S.O3. QUARTZ.

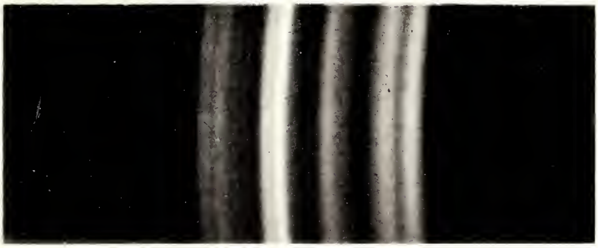
SILICIC FLUORIDE.

Plate XXXVI.

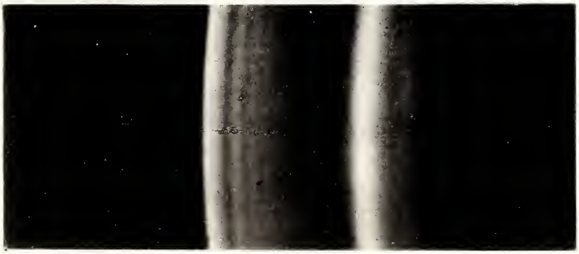
SiF_4.

SAME. QUARTZ.

TIN CHLORIDE. QUARTZ.



IODINE VAPOUR. QUARTZ.

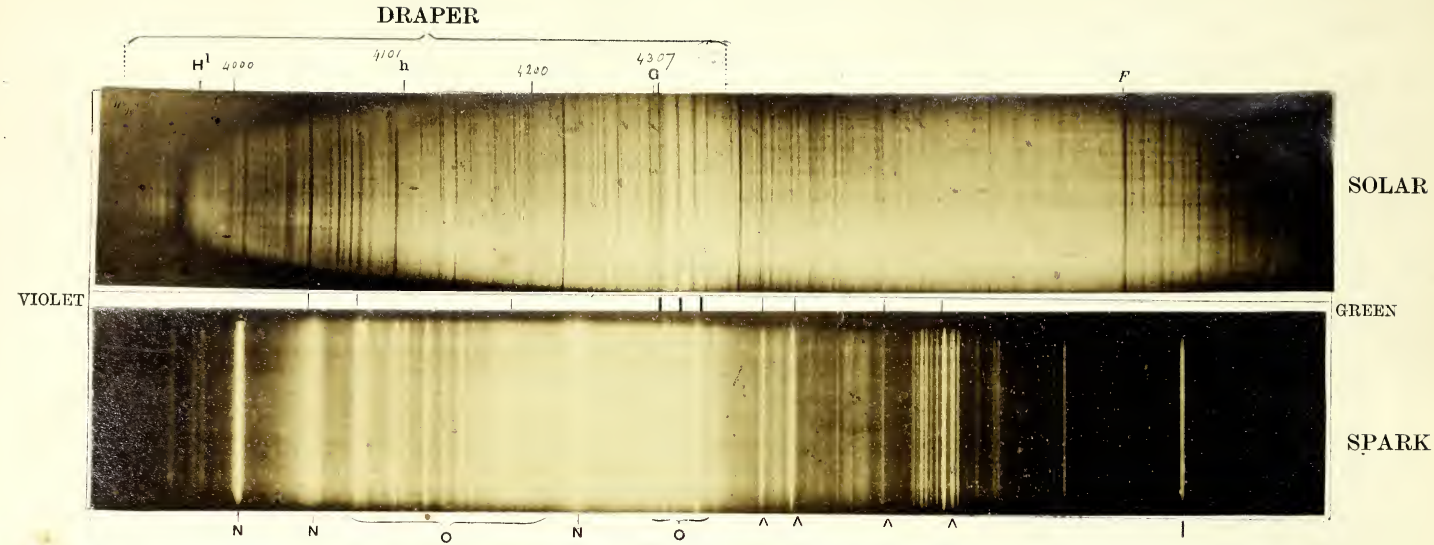


SPARK IN IODINE VAPOUR.

R. oniarga

R

Jan. 27



Solar Spectrum and Spark in air compared for the purpose of shewing position of bright lines in the former assigned by Professor Draper to Oxygen. These lie towards the violet end of the Spectrum, and are included within the bracket placed over the Solar Spectrum. The lines marked O and N in the Spark Spectrum are respectively Oxygen and Nitrogen. Other bright lines are seen more towards the green end in both Spectra, which are not included in Professor Draper's photograph. Spectroscope employed—a Browning compound (5) direct vision prism, 6-inch collimating lens of 1-inch aperture, and 9-inch projecting lens ; spark obtained from a 2-inch Rhumkorff coil, with condenser worked by four half-gallon bichromates. The photographs are untouched enlargements upon a scale of about one-half size of those of Professor Draper, and include the Spectrum from near H^2 to nearly *b*. Photographed by J. Rand Capron and G. H. Murray, and enlarged and printed by the latter.